ENVIRONMENTAL EFFECTS OF THE OPERATION of SULPHUR EXTRACTION GAS PLANTS IN ALBERTA

SUMMARY OF THE PUBLIC HEARINGS

OCTOBER, 1972

ENVIRONMENT CONSERVATION AUTHORITY

ALBERTA

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FOREWORD

The land surfaces of the Province of Alberta are varied, richly endowed, and extensively used for agriculture, for forestry, and for recreation, virtually over its entire area. On the other hand, below the surface, and again throughout the Province, seam upon seam of coal is found as well as oil, gas, tar sands, and other minerals. To simultaneously possess valuable though non-renewable resources below the surface and to enjoy abundant ever-renewable surface resources makes the Province twice blessed. At the same time problems can arise when the various surface and subsurface resources are used in ways which are not compatible with each other. An important factor is how these uses and the conflicts between them affect the livelihood and the well-being of the citizens.

The nature of the impact that subsurface resource developments can have on the surface regions depends directly on the nature of the subsurface resources that are being developed. Surface mining to recover coal creates rather a different disturbance than boring a hole to great depth to recover oil or gas but there are other factors to consider. Coal in Alberta possesses rather low sulphur contents which is a distinct advantage. By contrast some of the natural gas deposits in Alberta are highly sulphurous.

Hazards can arise from the release to the surface of these potent gaseous mixtures which may include besides hydrocarbons, compounds like hydrogen sulphide, mercaptans and carbon dioxide intermixed with water which may have salt dissolved in it. Unlike coal which as a solid is easier to contain within a given space, these gases and liquids, once released from their underground confinement, can, unless they are closely managed, become widely dispersed and have profound and widespread effects on the air, the land, the water and on people. For this reason, of course, they are closely managed. The oil and gas industry is a technologically intensive industry in all its aspects. This becomes even more marked

when sulphur is present in natural gas. This element in several of the forms it can assume, is known to have profound effects on living species in both plant and animal kingdoms.

The Environment Conservation Authority had been requested by the Government of Alberta to conduct comprehensive and wide-ranging hearings on the impact on the environment of resource development in Alberta. The Authority has recently completed its Report and Recommendations on the Impact on the Environment of Surface Mining in Alberta and this was tabled in the Legislative Assembly in the fall session of 1972.

In this continuing series of public enquiries, the Authority next directed its attention, at the request of the Honourable Mr. Yurko, the Minister of the Environment, to the environmental effects of the operation of sulphur extraction gas plants. There had been a considerable history of concern amongst citizens as to how their lives and livelihoods were being affected by the operations of the sour gas industry in their immediate neighbourhoods.

As a background to the public hearings, the Authority released its terms of reference, a prospectus on the subject of the hearings and a comprehensive review of the Environmental Effects of the Operation of Sulphur Extraction Gas Plants by Dr. R.F. Klemm.

The Klemm Report brought together all relevant and known information about the operations of sulphur extraction gas plants and the physical and regulatory conditions under which they operate. It analyzed the sources within these plants of possible environmental contaminants, discussed the methods and efficiencies of sulphur removal, and summarized what was known as to the effects of pollutants on air quality and human health, on farm livestock, on vegetation and on soil. The Klemm Report was circulated widely prior to the hearings and became an important basis of information for the public enquiry. Supported by this background work, the Authority then held hearings during October, 1972 in Pincher Creek, Red Deer, Whitecourt, Calgary and Edmonton.

A complete report of all submissions to the hearings, including the Klemm Report, as well as the discussions which followed, are contained in a separate publication entitled "Environmental Effects of the Operation of Sulphur Extraction Gas Plants - Proceedings of the Public Hearings." This publication is in three volumes and is available from the Authority at six dollars per set.

The present publication provides a summary of the Public Hearings and it contains, in addition, a critique of the hearings by the Science Advisory Committee of the Authority.

A third publication contains the Report and Recommendations of the Environment Conservation Authority on its public enquiry into the Environmental Effects of the Operation of Sulphur Extraction Gas Plants.

DR. W.R. TROST
Chairman
Environment Conservation Authority

ACKNOWLEDGEMENTS

The contribution that a Public Hearing can make to the advancement of any subject depends very largely on the submissions, briefs, and presentations made to it by members of the public. The Environment Conservation Authority is very appreciative of the considerable effort of individuals, groups and associations in preparing their submissions to the hearings, and indeed in acting to bring about the hearings themselves.

It is also most helpful and desirable if those who prepare submissions can have ready access to relevant information dealing with the subject under enquiry.

The Authority wishes particularly to acknowledge the invaluable and highly competent contribution made by Dr. Roger Klemm in his report on the Enviromental Effects of the Operation of Sulphur Extraction Gas Plants which was widely used by many people before, during and indeed after the hearings. The Environment Conservation Authority is most appreciative of the arrangement entered into by the Research Council of Alberta whereby Dr. Klemm was released from his normal duties to undertake this important project.

To its own staff the Authority expresses a special word of thanks for the many extra hours of effort they contributed to the hearings as well as for their valuable researches, advice and commentaries and for their help in preparing, assembling and producing this and the other post-hearing reports.

The Authority also very much appreciates the thorough and thoughtful way in which the submissions were prepared and presented throughout the hearings. There was inevitably a protagonist element associated with the hearings, and in some cases a history of past conflict not yet always resolved in a mutually satisfactory way. The Authority notes the additional element of courage required of an individual who speaks only for himself, and commends those citizens who took upon themselves this lonely and difficult task. The Authority also very much appreciates the thorough, candid

and objective way in which the industry analyzed its own operations and attempted to objectively assess the environmental effects of its operations.

Important and in some cases quite original contributions were also made by highly expert individuals either on their own disinterested behalf or as spokesmen for groups or associations. The opportunity to see these different facets of the problem put together under questioning and examination by the Authority so that it made a complete well-balanced though complex story was a welcome and salutary experience.

Above all, the Authority wishes to commend the citizens of the Province for the direct, honest, effective and reasonable way in which they approach problems that are not simple and involve conflicts between vital and personal interests.

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1. INTRODUCTION

INTRODUCTION

The Oil and Gas Industry has played an important role in the development of Alberta's energy resources and in this manner has contributed considerably to the economic development of the Province. Alberta today is the supplier of a major fraction of the energy needs for Canada; the future energy requirements of the country will see additional development of the oil and gas industry, together with developments in the Athabasca Tar Sands and coal fields. These latter sources will be tapped as supplies of conventional crude oil and natural gas diminish.

Natural gas is used extensively in Western Canada as a fuel because it is clean burning, causes little pollution as contrasted to other fuels, and has been relatively inexpensive. However, the raw natural gas as it exists in the earth is very often associated with the extremely dangerous compound hydrogen sulphide (H_2S), and this must be extracted prior to the gas being marketed. Some fifty-five percent of the natural gas produced in Alberta is obtained from sour gas fields. Hence the gas industry has had to design plants to remove the hydrogen sulphide and convert it to a more saleable and less objectionable product -- sulphur.

The gas industry has had special problems with sour natural gas, as the technology of processing had to be developed in Alberta, there being nowhere else in the world where such large quantities of sour gas were being used. During this development of the industry there has been considerable reaction from citizens living near gas plants. The government and industry have received indications from citizens that they were in one way or another being affected by gaseous or liquid effluents as a result of plant operation. Investigations have been carried out by both government and industry, with the result that in the recent past more stringent regulations governing industry activities have been brought into force.

To focus public attention on the issue and to allow for free exchange of information on the present environmental situation with

respect to sour gas plants, the Minister of the Environment, the Honourable W.J. Yurko, early in 1972 requested the Environment Conservation Authority to hold public hearings. The hearings were to investigate The Environmental Effects of the Operation of Sulphur Extraction Gas Plants and were to provide an unstructured input of information from the public, industry, municipalities and concerned organizations. From this the Environment Conservation Authority would prepare recommendations to be presented to the Government.

1.1 SITUATION REPORT

The Environment Conservation Authority endeavours to provide a situation statement prior to a public hearing. The purpose of this report is to focus on issues of importance to the subject of the hearing and to provide sufficient information to assist participants in the preparation of their briefs.

In this instance the Environment Conservation Authority was fortunate in obtaining the services of Dr. Roger F. Klemm. Dr. Klemm was seconded to the Authority by the Research Council of Alberta where he is a research chemist. During the preparation of the report and also during the hearings Dr. Klemm was relieved of his duties at the Research Council to devote his full time to the Authority. The Authority is most appreciative of this arrangement.

The terms of reference upon which the situation report was based were as broad as possible: plant operation; economics; treatment of chemicals; effects of emissions on humans, livestock, vegetation, inanimate objects; legislation affecting the industry; environment protection measures and monitoring techniques. Material for the report was obtained from the literature, from industry, from Government files by the use of a Task Force of civil servants, and from researchers with a special knowledge of environmental aspects; additionally Dr. Klemm toured several representative plants and visited one large plant for a week. The report was reviewed by several government committees before it was released as a public document.

1.2 TERMS OF REFERENCE

The overall term of reference for the hearings was to consider environmental effects:

> The effects on the environment of operating sulphur extraction gas plants in Alberta include all effects on materials and on living processes, including beneficial effects, of all developments and manifestations leading to the production of the gas, its treatment and the transportation to and consumption of all products by a customer.

Of major concern were the effects of elemental sulphur and sulphur compounds, such as hydrogen sulphide and sulphur dioxide. To also be examined were plant operations, the working environment, and also side effects such as noise or the effect of meteorological conditions. As stated, the objective of the hearings was:

> Through public hearing to enquire into all effects on the environment of the operation of sulphur extraction gas plants in Alberta, and to review all legislation pertaining thereto; and to lay the views presented to the Authority and the Authority's recommendations thereon before the Lieutenant Governor-in-Council through the Minister of the Environment.

1.3 LOCATION OF HEARINGS

Sulphur extraction gas plants are found concentrated mainly in a band from Calgary to Red Deer and extending west into the Foothills and in a loose grouping west of Whitecourt; there are also several locations outside this general area in which one or two plants are found. To obtain input from the population affected by plant operations without the necessity for inconveniencing individuals through travelling or interference with their working schedules, the hearings were set for five locations. They were also held in October, after what was expected to be a normal harvest date. Hearings were held in:

Pincher Creek	-	October 2, 1972
Red Deer	-	October 5, 1972
Whitecourt	-	October 11, 1972
Calgary	-	October 16, 1972
Edmonton	-	October 19, 1972

1.4 FORMAT OF HEARINGS

The Environment Conservation Authority holds what may be considered rather informal public hearings; the object is to allow the participants to feel relaxed and be able to freely express their opinions. At these hearings, the Authority was represented by the Chairman, Dr. W.R. Trost; Dr. S.B. Smith, Member,and Mr. W. A. Flook, Research Co-ordinator. Each hearing opened with a presentation by Dr. R.F. Klemm of highlights from his report. Following this, briefs were presented and upon completion members of the panel questioned the participants to highlight subject matter or raise particular issues. Time was also allotted at the end of each hearing for a general discussion. Activities during the hearings were recorded by tape recorder and videotape from which transcripts were be made.

1.5 REPRESENTATION AT THE HEARINGS

The participants in the hearings may be divided into four categories for illustrative purposes: individuals in proximity to or affected by gas plants; government such as county councils; industry; individuals and associations concerned about the environmental impact of sulphur extraction gas plants. Each hearing had a different weighting in the presentations made; such might have been expected due to the hearing location. Pincher Creek and Red Deer briefs were mainly from residents and the industry, in Calgary and Whitecourt they were mostly from the industry, while in Edmonton associations submitted most of the briefs. In addition to the public submissions, there were several received at the Authority offices for inclusion

in the records. In total, there were sixty-one briefs submitted to these public hearings. Following the categorical description given above, the numbers of briefs presented by each were: individuals near plants, 13 briefs; government and municipal representatives, 7 briefs; industry (including the C.P.A.), 17 briefs; individuals and associations, 24 briefs (8 individuals, 16 associations).

1.6 POST-HEARING REPORTS

The Authority must prepare four documents as records of the hearings. A verbatim Transcript of the dialogue is prepared from the tapes; copies of this are kept in the offices of the Authority and Government. Proceedings, containing the submitted briefs and an edited version of the questioning periods, is made available to the public at a nominal charge. A concise objective Summary of the input to all hearings is prepared to indicate the consensus of opinion. Finally, the Report and Recommendations of the Authority is written and presented to the Government; this becomes a public document after it is tabled in the Legislature.

1.7 FORMAT OF THIS SUMMARY

This Summary is intended to provide an objective condensation of all oral and written input to the public hearings. As the task is to present an overview of the issues raised and discussed, individual briefs are not summarized in themselves, rather they are assimilated into the set of statements, concerns and recommendations that form the general consensus of opinion. In general, individual briefs will not be identified or commented upon other than to indicate the category into which they fall. There are two exceptions, however: the Situation Report and the Canadian Petroleum Association (C.P.A.) brief. The Situation Report by Dr. Klemm covers in some instances material which was either not discussed at the hearings or was mentioned only briefly, moreover, it serves as an additional

source of information because of the research required for its preparation. The Canadian Petroleum Association brief was prepared by a team of consultants and as such stands as representative of the industry viewpoint. The Canadian Petroleum Association brief contains considerable material on research, the impact of legislation, and the activities of industry in the Province. Several briefs from individual plant operators also indicate their concurrence with Canadian Petroleum Association statements and as such this brief is mentioned when necessary.

The Summary has been arranged to bring into focus the various facets of different environmental concerns: stack emissions and their effects on humans, animals or vegetation, elemental sulphur, research projects, effect of legislation, solid and liquid economics of operations, citizen-industry government interaction, and other topics which can be separately identified. Each section is addressed as much as possible to an individual topic; however, the interactions of all issues requires that some overlap and cross-referencing occur.

1.8 SELENIUM REPORT

Because of the importance of selenium in exactly the right quantity in animal nutrition, and its special chemical interrelationships with sulphur, the Authority commissioned a staff report on the subject of these relationships. This report is being published separately but is also included in its entirety as Chapter 4 of the present publication.

1.9 SCIENCE ADVISORY COMMITTEE CRITIQUE

In order to obtain an independent critical commentary of the hearings by informed observers, the Authority requested its Science Advisory Committee to prepare a document in which it was invited to comment freely on any and all aspects of the hearings as it saw fit.

The document submitted to the Authority is reproduced in its entirety as Chapter 5 of the present report under the title "Science Advisory Committee Critique of Submissions to the Public Hearings."

2. SUMMARY
of the
PUBLIC HEARINGS

2.1 THE SOUR GAS INDUSTRY

It is worthwhile before involving the reader in the actual summary of briefs and oral dialogue at the public hearings to provide a brief outline of the subject matter. The material for this section has been excerpted from the Situation Report and the Canadian Petroleum Association brief.

2.1.1 History

Gas was discovered in Alberta in 1914, but the first natural gas plant, at Turner Valley, was not constructed until 1933. The gas processed in the early days of the industry contained a small percentage of hydrogen sulphide (H_2S): gas of this nature is "sour" when the hydrogen sulphide must be removed before sales, after removal the sales gas is "sweet". The early gas plants did not recover elemental sulphur, rather they extracted the hydrogen sulphide and flared (burned) it to the atmosphere. The first plant to recover sulphur, built at Jumping Pound in 1951, processed a stream containing 3-4% hydrogen sulphide; in 1957, completion of a pipeline to the east and increased markets permitted additional plants to be built. Some of the plants of the fifties processed sour gas of 35% hydrogen sulphide, while at present the maximum stream is approximately 50% hydrogen sulphide. The new plants also were larger in design capacity, even in the early sixties two were built to extract up to 2000 long tons per day (LT/D) of sulphur. Today, out of a total of 150 gas plants in Alberta, 67 process a gas which is sour, yet these account for over half of all the gas processed. Forty-two of the sour gas plants extract elemental sulphur while the remainder flare the hydrogen sulphide.

2.1.2 Economics

The oil and gas industry has become extremely important to the economy of Alberta. An estimated 50% of total personal income is derived

from this combined industry. Over the years a physical capital investment of $800 million has been attributed to the natural gas industry alone. The industry is highly capital intensive, employment in the gas plants standing at about 5000 personnel, yet the job multiplier effect (no figures given) swells this number considerably. In addition to employment, the industry contributes through royalties and taxes substantially to municipal and provincial treasuries.

Sulphur prices have fluctuated over the years. In 1960 sulphur commanded $20 per long ton (a long ton is 2200 pounds) and this had decreased to $10 by 1964. A rapid price escalation occurred between 1965 and 1968 owing to the demand by new markets, and the price peaked at $34.53 per long ton. Owing to circumstances, such as the much increased production capacity of Alberta producers and competition from other sources, prices dropped more rapidly than they had risen, and in mid-1971 a low of $6.41 was received per long ton.

The current sulphur price, combined with growing stockpiles and of prospects for future market makes future production unattractive. Indeed, in new construction, sulphur is valued at $0.

2.1.3 Sulphur Production

Production of sulphur has risen sharply over the years. In 1957 only 45,000 long tons were produced; by 1963 this had increased to 1.3 million long tons per year and in 1971 total output was 4.5 million long tons. The year 1976 may see 9 million long tons being produced. Stockpiles are also growing: there were approximately 5 million long tons sitting by plants in 1971; the inventory is estimated to be 10 million long tons by the end of 1973 and 25 million long tons by 1976. Research is currently underway to find new uses for this sulphur.

Sulphur extraction is not 100% efficient; however the industry average is a 95% recovery efficiency, considered to be high. Consequently, the hydrogen sulphide not converted to elemental sulphur is burned and emitted to the atmosphere as sulphur dioxide (SO_2). Average daily

emission of sulphur (as sulphur dioxide) into the atmosphere over Alberta at present is approximately 600 long tons.

2.2 REGULATORY AGENCIES

The Government of Alberta has vested in the Department of the Environment overall responsibility for environmental matters pertaining to the gas industry. The Department also is responsible for determining standards and has final authority in approving all plans and specifications to ensure environmental protection standards are not exceeded. The industry has an effect on air, water (surface and subsurface) and land; consequently it comes under the jurisdiction of the Department of Lands and Forests and the Department of Mines and Minerals.

The Energy Resources Conservation Board has been delegated responsibility for devising and administering the ways and means required to ensure pollution control standards are met. In effect, E.R.C.B. is the principal communication link with the industry on pollution control matters. Plant operators must report to the Board on a regular basis concerning many phases of their operations; the Board has field inspectors throughout the province and investigates complaints (as does the Department of the Environment) brought to its attention. The Board in 1971 issued a directive which required an increase in the recovery efficiency of many gas plants; this subject was given considerable attention at the hearings and will be discussed in this report. Funding of the oil and gas operations of the Board is split 50-50 between the industry and the provincial government.

2.3 PLANT OPERATION

Sour gas is extremely poisonous and corrosive; consequently all equipment used in the processing must be noncorrosive and reliable. Safety practices and the danger of the industry can be compared to others by observation of the Workmen's Compensation Board assessment rates: the low assessment attests to the safety conscious attitude of the industry.

Raw natural gas is a mixture of hydrocarbons such as methane, ethane, etc., produced water, hydrogen sulphide, carbon dioxide, and nitrogen; trace amounts of other gases may also be present. Hydrogen sulphide may vary from trace quantities (sweet gas) to the maximum that has been discovered to date, approximately 90%.

Gas enters a plant at high pressure, usually about 1000 psi, where it is first separated into three phases; sour gas, produced "sour" water and the hydrocarbon liquid phase (condensate). Both water and condensate are then stripped of the dissolved gases, the water is returned to the underground formation (if in excess of 100 barrels per month) or disposed to a storage pit while condensate is further processed for market. Reversible selective absorption in an aqueous solution of an amine is the method used to remove acid gas (hydrogen sulphide and carbon dioxide) from the sour gas. Acid gas is then removed from the amine solution and directed to the sulphur plant.

The sulphur plant essentially burns hydrogen sulphide to sulphur through a series of reactions. Acid gas first enters a furnace where air is added to burn a fraction of the gas to sulphur dioxide; in the furnace about 50% of the hydrogen sulphide is also converted to elemental sulphur. The gases are then cooled to liquify the sulphur (drained to storage) and fed into the first of a series (maybe up to four) of Claus converters. In each converter hydrogen sulphide and sulphur dioxide react on a catalyst bed to provide elemental sulphur. Reaction of hydrogen sulphide is never 100% complete; consequently all unreacted gases are fed to an incinerator to be combusted, and the final product of the conversion, sulphur dioxide, is vented to the atmosphere through the incinerator stack. Liquid sulphur flows into a holding pit, from where it is sent to tank cars or solidified in the sulphur storage pile.

2.4 ATMOSPHERIC EMISSIONS

Environmental effects of atmospheric emissions from sour gas plants stacks were a major topic of concern at the public hearings. A consideration of this problem is rather complex in that it is difficult to establish a cause and effect relationship. On the one hand, industry stated there has been some damage to vegetation from atmospheric emissions but that no evidence exists to prove there have been any effects on humans or animals. On the other hand, many individuals who presented briefs and resided near gas plants focused their attention on the damage that has occurred to humans, to domestic animals, vegetation and inanimate objects. In addition, several associations and municipal government representatives expressed concern over harmful effects. There were also briefs indicating some gas plants have had little if any adverse effect on the surrounding environment. This section will summarize the various viewpoints on atmospheric emissions as they were reported at the hearings to affect human and animal health, vegetation and inanimate objects. The two most comprehensive reports presented at the hearings, the Situation Report and the Canadian Petroleum Association brief, each contain chapters describing environmental effects and these are summarized below.

2.4.1 Human Health

Over half of the briefs presented at the hearings discussed the situation with respect to the effect of gas plant emissions on human health. It will be noted that there is considerable disagreement between industry and gas plant area residents as to the effects of these emissions

2.4.1.1 The Situation Report

The Province of Alberta has ambient air quality standards (allowab levels of pollutants in the atmosphere) that are based on the direct effec of pollutants on human, animal and green plant vitality. The standards

applicable to hydrogen sulphide and sulphur dioxide, the two main gaseous pollutants emitted by sour gas plants, are as follows: 0.01 ppm (parts per million) maximum for thirty minutes, 0.005 ppm average for 24 hours for hydrogen sulphide; 0.2 ppm maximum in urban and arable agricultural land and 0.3 ppm maximum in all other areas for thirty minutes; 0.1 ppm average for 24 hours for sulphur dioxide. There was some concern expressed in the Situation Report for the fact that these levels are determined by the effects of a single pollutant and may neglect such things as possible synergistic interactions with other chemicals, varied reactions with people, the effect of weather conditions on pollutants, and the possibility of pollutants being transmitted by other pathways. It was also indicated that more attention is given to the short-term effect of exposure to a harmful substance than to a long-term effect. Furthermore, the report stated that there are many other possible contaminants associated with the operation of sour gas plants for which little information is available and which are not normally monitored. In fact only hydrogen sulphide and sulphur dioxide are tested on a regular basis in gaseous effluents.

Both sulphur dioxide and hydrogen sulphide are detectable by odour. Sulphur dioxide can be detected at concentrations as low as 0.3 to 1.0 ppm, principally by taste, and studies have shown 1.0 ppm of sulphur dioxide for five hours can cause bronchospasms (constrictions of the muscles of the lung by spasmodic contraction) in sensitive people. Hydrogen sulphide can be extremely odorous and is detectable at concentrations as low as 0.03 ppm by sensitive people, but the literature is confused regarding the lowest concentrations detectable. Other possible atmospheric contaminants associated with the operation of sour gas plants are carbonyl sulphide, carbon disulphide, heavy hydrocarbons, mercaptans, selenium, mercury and lead. All of these compounds may be in the raw sour gas or, as is the case for the first two, formed in the reactors. Some of the latter contaminants may enter the environment in the plant liquid effluents. It was noted in the Situation Report that little is known about the effects of these substances, although

tests for selenium and mercury in sour gas and plant wastes indicated that they are present only in minute quantities. Of all the gaseous compounds that may be emitted from sour gas plants, only hydrogen sulphide and sulphur dioxide are required by the Department of the Environment to be tested for on a regular basis.

2.4.1.2 Industrial Submissions

One section of the Canadian Petroleum Association brief was devoted to an analysis of information available on urban air pollution and research into the effects of sulphur dioxide on humans. The brief stated that populations exposed to sulphur dioxide in concentrations from 0.5 to slightly over 2 ppm do not show direct evidence of increased susceptibility to respiratory infection attributable to the effects of this gas. It was noted that one investigation indicated that sulphur dioxide is not specifically related to aggravation of chronic bronchitis.

Research has shown that sulphur dioxide may react on moist particles to form sulphuric acid mist or sulphur trioxide, each of which is more often irritant than sulphur dioxide. Conversion of sulphur dioxide to these two compounds in the atmosphere is a slow process and levels attained would be well below that for measurable effects on health. The brief stated that other air pollutants, such as hydrogen sulphide or mercaptans, were viewed as occasionally constituting an odour nuisance.

The conclusion of the C.P.A. brief was: "the effect of urban air pollution on the health of exposed populations as found in acute pollution episodes and in other instances of relatively high pollutant concentrations does not appear to involve sulphur dioxide in its mechanism." It was stated at the hearings by a C.P.A. consultant that thousands of measurements throughout the province indicate that no situation anywhere has resulted in concentrations of sulphur dioxide which were hazardous to health.

Most briefs presented on behalf of individual plants indicated

support for the C.P.A. submission. It was stated in four briefs that the individual plant had received only a few complaints, principally concerning odours, while one brief indicated that no complaints have been received in the past while at the plant. Personnel from one plant visit residents of the area on an annual basis to explain the operations and emergency procedures; other operators who are questioned on this point indicated they did not have a regular community information program.

Representatives from Great Canadian Oil Sands (not a gas processing plant, but one which must recover sulphur) cautioned that while there was not a health hazard present, future recovery plants in the Fort McMurray area may create environment problems. Most of the industrial submissions stated that present ambient air quality standards were adequate to protect the health of humans and to prevent undue environmental damage. It was also recommended quite often in the briefs that standards should not be made more stringent.

2.4.1.3 Gas Plant Area Residents

Briefs commenting on air pollution effects were received from thirteen individuals who represented their families and from five individuals or associations representing several people. The majority of these submissions stated that gas plant emissions had affected the health of individuals and in most cases it was indicated that the situation was improving. Several of the briefs did indicate, however, that no apparent environmental damage could be attributed to particular gas plants.

Individuals who had suffered considerable health damage which they attributed to gas plant emissions presented briefs in Pincher Creek, Red Deer and Calgary. These individuals generally live in close proximity to gas plants, some within one mile of a plant, and one family noted that they live within a ten-mile radius of four plants. All familes who have suffered health impairment that they attribute to gas plant emissions stated that their problems did not begin until soon after plants were built. For some residents this was as long ago as 1957. While most of

the individual family representatives stated that pollution occurrences and odours are not as bad or as frequent as in the past, they indicated that there are still instances when odours are present and individuals may experience recurring symptoms at that time.

There were also reports of families having to move away from the vicinity of a gas plant. Two residents in the Pincher Creek area moved from their homes in the mid 1960's: one family moved out of the area while the other family moved to a part of their property farthest from the plant. Members of both families continue to experience symptoms if downwind from the plant.

In the majority of cases individuals who felt that emissions were causing health damage noted that the symptoms were respiratory in nature although there was a wide variety of ailments. A listing of the symptoms include a burning nose, throat and lungs, dry cough, sinusitis, bronchitis, emphysema, stuffiness, itching and burning eyes, nose-bleeds, headaches, dizziness, extreme tiredness and restless sleep, possible allergic reaction and skin rashes, and indigestion. In the Pincher Creek area these symptoms were most severe in the late fifties to early sixties but the residents still occasionally experience respiratory or eye irritations. Three briefs contain comments to the effect that while the resident had not experienced severe problems there are times when individuals have to stay out of a gas plant area because of the strong odour.

It was stated in two submissions that there may be a relationship between the severity of symptoms experienced and the age of the individual, as children appeared to suffer more than adults. It was also mentioned that people exposed to pollutants over a long period of time may become sensitized to these pollutants and could experience symptoms when exposed even to low concentrations that are considered safe for the general population.

A problem experienced by all individuals who believe emissions have caused health impairment has been to prove that the emissions actually have caused the physical ailment. Only one official government investigation

of the situation has been undertaken. This was in the Pincher Creek Area in the early 1960's and the conclusion reached by the committee was that there was no evidence that health problems could be attributed to gas plant emissions. It has been necessary for the individual to use his own resources in attempting to determine if the gas plant emissions are affecting his health. This has caused considerable hardship in most cases.

Each individual gas plant must be considered on its own merit. This was illustrated by two briefs that were submitted , each of which was signed by approximately twenty-five area residents near two individual plants. One plant was cited as causing severe odours which affect the people and animals and also was responsible for vegetation damage; the other plant was considered to be a valued member of the community and the residents offered no complaints. In addition to the two above submissions, another brief contained statements from five residents that two new plants in their area have been responsible for emitting odorous compounds which have caused them headaches, nausea and eye irritation.

Prior to the hearings, UNIFARM mailed a questionnaire to 322 of its members who resided in the vicinity of gas plants. There were 63 replies to this questionnaire. Concerning a question about noticing plant odours, 22 replies stated yes and 29 stated no; in some cases the respondent lived at least 10 miles away from a plant. From the results of the questionnaire, UNIFARM concluded "the effect of sulphur on land, crops, livestock, and human health does not give sufficient evidence to indicate any particular effect."

2.4.1.4 Other Submissions

Of the five counties and towns represented at the hearings, in only two of their submissions was it stated that councillors believed gas plants had affected human health. In the latter two submissions it was noted that these problems were more severe in the past and that the situation is now much improved.

Three separate briefs recommended that additional research into health effects be undertaken as the authors believed there was sufficient evidence available to indicate people have suffered from gas plant emissions. The lawyer who had represented residents in a law suit against one gas plant expressed concern about the standards that are set for air pollutants. He pointed out that the standards assume that all people react similarly to a given level of pollutant and that high-level concentrations occurring episodically are often neglected by the fact that standards are set for average levels. He also noted that in his investigation he found some residents of the area in question to be affected by gas plant emissions while other residents were not.

2.4.2 Effects of Gaseous Emissions on Vegetation and Soils

Scientific evidence has shown that vegetation can be quite sensitive to airborne pollutants. At the hearings the gas industry offered considerable information on studies being undertaken in Alberta to examine the effects of emissions on living plants. Twenty briefs discussed this subject; the major source of damage was sulphur dust blowing from storage areas (to be discussed in section 8) but there is evidence for slight stress on vegetation due to sulphur dioxide emissions from some gas plants. Although the effects on vegetation are viewed by the industry as not being permanent, concern was expressed by individuals and organizations.

2.4.2.1 Industrial Submissions

Research has shown that vegetation damage resulting from gas emissions has been minimal and transitory in nature according to the evidence presented by industrial consultants. The C.P.A. brief stated that sulphur dioxide emissions near gas plants have been below lethal levels for the main tree species and that there has not been any evidence

of crop damage occurring in the Province. The Association also felt that emissions were beneficial to vegetation, as evidenced by the following investigations. Studies have shown that green plants can absorb low levels of sulphur dioxide which, when oxidized to sulphate in the plant, serves as a nutrient. Sulphur dioxide is also oxidized in the atmosphere and added to the soil as a sulphate in rainwater; studies have determined that two to six pounds of sulphur per acre are added in this manner to the soils of central Alberta. The brief stated: "The important consideration here is that in the growing season the sulphur emissions from Alberta gas plants are deposited within Alberta and utilized by crop vegetation."

Over half of the briefs submitted on behalf of individual gas plants discussed the impact of emissions on vegetation and concluded that slight vegetational stress had occurred in some instances, but the damage was not permanent. Sulphur dust was responsible for much of the soil sterilization in close proximity to several plants (see Section 8); however, in one case it was viewed as beneficial in that it lowered the pH of the alkaline soil; several plants are presently reclaiming soil affected by sulphur dust.

Industry has recently initiated studies by consultants into determining and monitoring the effects of emissions. Twelve gas plants in northwestern Alberta have formed the Whitecourt Environmental Study Group to study over a period of three to five years the effects in their area. Main findings to date have indicated some stress in poplar trees near several plants, but growth has not been hindered and the trees revert to their normal state when sulphur dioxide levels are decreased or become negligible. Similar investigations on vegetation near a gas plant south of Calgary detected stress on poplar and ash on a hill five miles south of the plant, and on willow north of the plant. The transitory nature of stress was noted in the fact that it was detected only in the latter part of summer. In this instance sulphur dioxide readings have indicated winds from the north carry this gas from another source. A third company reported a consultant's findings that no damage was detected in alfalfa, one of the most sensitive vegetational species.

One company has initiated a research program to test the effects of air pollutants on alfalfa, barley and brome grass grown under controlled conditions of soil, fertilizer, etc; test plots are inside and outside the emission zone. Results were not reported at the hearings.

2.4.2.2 Individual and Association Submissions

Briefs were received from six individuals directly affected by plant emissions and who attributed vegetation damage to gaseous pollutants. The effects described were whitening of alfalfa leaves in one case, trees affected (in two instances trees may have died as a result of air pollution),and in one case difficulty in growing house plants was experienced but yield of field crops was not diminished.

The Canada Department of the Environment expressed concern for gas plant emissions. A Department representative indicated that research has shown chronic injury to vegetation does result from prolonged exposures to a low concentration of only 0.03 ppm sulphur dioxide,and symptoms range from gradual foliar discoloration to growth defects. Also mentioned was the fact that 1.25 ppm sulphur dioxide for one hour can cause acute damage to alfalfa. It was recommended in this brief and in three other submissions that lichens, some of which are extremely sensitive to sulphur dioxide, be used to measure the extent of pollutants.

General concern for vegetation and the effects of emissions was discussed in several briefs. It was indicated that knowledge of the fate of pollutants is not extensive. In summer when vegetation is most susceptible, most of the pollutants return to earth within the province, but in winter when emission output is greater the same removal mechanisms are not acting. One brief stated that the appearance of stress in vegetation did not mean that the ambient air quality standards had been exceeded, as the maximum level of sulphur dioxide may have been reached for a period of time.

Sulphur is a necessary plant nutrient and as such the deposition of sulphur in the form of sulphate can be beneficial for much of the agricultural land in Alberta according to the Alberta Institute of Agrologists. Their brief indicated that in this respect gas plant emissions may be of help to agriculture; however, the Institute expressed a concern for a possible acidifying effect on soils over a long time span if the deposits are cumulative. On this basis it was recommended that research should determine the extent of deposition.

2.4.3 Effects on Animal Health

As is the situation with respect to human health, any cause and effect relationship between air pollutants and animal health has not been clearly established. The Situation Report indicated there have been cases where Department of Agriculture veterinarians have been called to investigate livestock damage which the owner attributes to gaseous effluents. The most common diagnosis is one of damage to the lungs (pulmonary emphysema) or irritant damage to the eyes, yet the cause can not always be determined. When cattle had access to plant effluents or drank water containing sulphur dust, the cause of damage has usually been determined.

Present ambient air quality standards are such that a health hazard for animals does not exist, according to the Canadian Petroleum Association submission. As evidence for this, the brief reported on scientific studies undertaken on dogs and guinea pigs. In these it was indicated that no detrimental changes could be found from prolonged exposure to sulphur dioxide at concentrations much higher than the ambient levels in Alberta. In contrast to these reported findings, the Canada Department of the Environment cites studies in which guinea pigs experienced slight increase in pulmonary flow resistance when exposed to 0.16 ppm sulphur dioxide; the changes were readily reversed when the gas was removed. Although there has not been any indication that emissions affect wild animals, one consultant thought they would move from an area if they sensed danger. Industry has not

studied the effects of emissions on animals, but one company has plans to compare the performance of selected animals inside and outside the emission zone.

Several briefs from individuals discussed cases of animals being stricken with health afflictions that the owner believed could be attributed to gas plant emissions. Such ailments as breathing impairment, loss of appetite, eye irritation and bleeding noses were mentioned; in Pincher Creek the average litter of hogs decreased in the early sixties and hogs are no longer raised by one family. In one brief, reference was made to a project in which the Alberta Department of Agriculture exposed various animals, including pigs, to sulphur dioxide and hydrogen sulphide. The experimental results did indicate that certain concentrations of these gases are harmful, usually to the respiratory system. One veterinarian had stated his belief that there were certain cases in which gas emissions could definitely be suspected as the causative factor of an affliction.

In one brief a veterinarian explored what may be considered an indirect effect of emissions on animal health. In central Alberta over the past several years there has been a considerable increase in the incidence of White Muscle Disease in animals, especially cattle. This disease is known to be the result of a selenium deficiency in the animal's diet, the diet generally consisting of a feed grown locally (selenium is taken into the plant through its soil root system). Documented research was noted as showing that sulphur fertilizers which promote plant growth also contribute to a lowered selenium concentration in the plant. The veterinarian therefore proposed that gas plant emissions, which are known to add sulphate to the soil, may stimulate plant growth sufficiently to decrease the selenium below a nutritionally acceptable level. The result would be increased cases of White Muscle Disease. He stated many farmers are confused as to the situation and recommended research to determine if such a relationship exists.

2.4.4 Damage to Physical Objects

Corrosion and deterioration of physical materials were mentioned in thirteen briefs from individuals or associations. In several cases fence wire had rusted at a faster rate after gas plants were built; strands of pitted or rusted wire were submitted by two individuals as evidence. Tarnished silver was often cited, paint blistering or blackening was mentioned and in several cases the individual now uses plastic clotheslines. Farm machinery was often found to be affected to a greater extent near gas plants. In a comparison of machinery and tractors in the Pincher Creek area and elsewhere it was found that differences did exist. The UNIFARM submission noted thirty replies to a questionnaire had indicated machinery was affected while sixteen said there had not been any noticeable effect, whereas paint was said to have been affected in seventeen cases out of forty-one. The only scientific evidence brought forth concerning corrosive effects was that a direct relationship existed between corrosion and a mean annual sulphur dioxide concentration from 0.03 to 0.12 ppm.

A total of 100 corrosion stations have been set up by at least nine gas plants. Generally each station consists of various metal strips, paint chips and wire; at one plant it also included rubber. Based on results to date, the most corrosive atmosphere appears to be associated with agricultural activities, with urban centers slightly lower. Rates around isolated sulphur plants have been the lowest of three areas.

2.5 IN-PLANT ENVIRONMENT

The interaction between humans and sour gas plants can be visualized as divided into two categories: that between the gas plant and the surrounding community, and that between the gas plant and its employees. Members of the surrounding community are generally affected only by gas plant emissions; however, employees are not only affected by emissions but also must be governed by certain safety regulations. Indeed, regulatory agencies which are responsible for the community and the plant

employees are different. Ambient air quality standards apply only to the community surrounding the gas plant and are the responsibility of the Department of the Environment. In-plant environment, on the other hand, comes under the control of the Workmen's Compensation Board, the Energy Resources Compensation Board, the Division of Industrial Health Services, and to some extent the Department of the Environment. In fact ambient air quality standards do not apply to the in-plant environment; rather threshold limiting values for gaseous pollutants are set and employees may be subject to these values for an eight-hour working day. For the two gases of consideration in sour gas plants, sulphur dioxide and hydrogen sulphide, the threshold limiting value is 5 ppm and 10 ppm respectively. The Situation Report indicated that gas plants do not have detection equipment for gases other than hydrogen sulphide and warning devices for this gas are set to indicate only an explosive mixture. The concentration of hydrogen sulphide for an explosive mixture is known to be much greater than concentrations which could affect an individual.

The industry viewpoint was that gas plant operations are very safe and this is based on the safety programs of the industry and the rating by the Workmen's Compensation Board. Each company provides for its employees instruction and training in detection of hydrogen sulphide, rescue, safety and first aid procedures. Safety training programs which deal with general plant operation are also given. Both the Canadian Petroleum Association and the Canada Department of the Environment stated that there is no medical evidence to indicate levels of gases encountered in sour gas plants have led to a deterioration of employee health. Four industry briefs commented on the involvement of workers in plant safety programs. In one plant the union does not play a direct part in safety and environmental programs while in two other plants workers are directly involved in organizing such programs.

In contrast to the industry viewpoint, the unions in their submissions expressed concern about in-plant environment and the role of the worker. It was stated that in the past three years fifteen fatalities and a total of 337 accidents were related to hydrogen sulphide. It was

also stated that workers may be afraid to report environmental or safety problems because of the threat of company repercussions. The effectiveness of the Division of Industrial Health Services was also questioned and a recommendation was made that environmental committees, consisting of management and employees, be established for each plant. The unions could also not understand the reason for such high levels of gaseous pollutants allowed on the plant sites while the ambient air quality standards applied everywhere but at the plant. Only one association discussed the in-plant environment and statements made by the association agreed in general with the concerns of the unions.

2.6 CITIZEN-INDUSTRY-GOVERNMENT INTERACTION

In any area of human endeavour in which there is an interface between various groups, there is bound to be some reaction to the activities of each group. Approximately half of the briefs submitted to the hearings contained some comment about relationships existing between citizens, the industry and the government. In general, citizens are not too satisfied with government and industry response to their concerns, whereas industry feels that its community relations have been good but that there should be more cooperation with government.

Much of the discussion by individuals and associations centered around the belief that industry and government have displayed little cooperation at times in attending to the concerns of individuals who feel they have been affected by gas plant operations. As an example, a government report issued in 1963 indicated that an investigation had found no evidence that gas plants in the Pincher Creek area had any effect on the health of humans. The Municipal District of Pincher Creek submission mentioned that the credibility of the government was destroyed because citizens were not involved in the investigation. Subsequent to the issuance of the above report a lawsuit was instigated out of court. The lawyer who represented the plaintiffs in this lawsuit stated at the hearings that it was only with considerable difficulty that he was able to obtain information from the government.

Several individuals stated that in certain cases plant personnel were very un-cooperative and in interactions with the government the individual often had to wait a considerable length of time for any action. Municipal representatives in general believed that a good relationship existed between the gas plants and the municipal district or town. An individual who had surveyed residents living around one gas plant stated that none of the residents had any complaints. A total of four briefs discussed the affect of gas plant operations on land value and of these three briefs stated that the value had decreased, whereas the fourth indicated there had been no deterioration in land value around a particular plant.

Of great concern to a number of individuals and associations was the necessity for someone who has been affected by gas plant operations to prove his case. About ten briefs which discussed this subject stated that this imposed a very heavy burden on the individual. Not only could this be a financial burden but it would also cause a great deal of personal suffering. These briefs were also in agreement that the onus of proof should be on the industry or government to show that there will be no environmental degradation.

Many of the individuals who addressed themselves to the topic of their relationship with industry or government expressed a great frustration with these bodies. This was often stated emphatically in the oral presentations. For some the situation had reached a point where they did not know to what agency they could turn. Very often a strong recommendation was made for a more thorough investigation of the environmental effects of plant wastes.

The Canadian Petroleum Association brief and at least half of the submissions by the industry discussed citizen-industry-government interaction; the consensus of opinion was that the industry and individual gas plants are good corporate citizens of Alberta. Several operators stated that their companies accept full corporate responsibility for environmental

protection. Although most gas plants do not enter into consultation with the community one spokesman indicated that personnel from his company visit all farms in the immediate area on an annual basis and that community relationships are excellent. The companies were also in agreement that there should be consultation between industry and government on regulations governing the industry, that there should be cooperation between industry and government and associations in research programs. At present none of the plants do, however, involve the community in their programs. A Canadian Petroleum Association representative stated, and it was also mentioned in one brief, that research results should be made public and there should be no secrecy on environmental matters.

2.7 REGULATORY AGENCIES, REGULATIONS AND MONITORING

2.7.1 General

The gas industry is regulated by a broad collection of regulations and guidelines, all of which are under a continual review. The Department of the Environment has jurisdiction over environmental matters and as such sets maximum permissible levels of pollutants. The Department also approves all plans and specifications to ensure that standards are not exceeded. The Energy Resources Conservation Board is delegated responsibility for devising and administering the ways and means required to ensure that the standards are met; the Board is funded equally by industry and government. In addition to the Energy Resources Conservation Board and the Department of the Environment, the industry is regulated in one way or another by the Department of Mines and Minerals, the Department of Lands and Forests, the Department of Health and Social Development, the Department of Manpower and Labour, and the Workmen's Compensation Board.

The present ambient air quality standards are set "... to protect the health and welfare of all citizens, enhance and maintain the quality of the Province's air resource and prevent insofar as possible deleterious

effects to animals, plants and property." Other regulations have been instituted in the past several years to protect water quality and prevent environmental degradation around industrial sites.

2.7.2 Individual and Association Viewpoints

Many of the briefs submitted by individuals and associations, of which there were approximately twenty that discussed regulations, expressed some concern for the effectiveness of present standards and regulations. In most cases recommendations were made for more stringent regulations and additional controls. Although the requests were made for more stringent regulations in general, in several of the briefs the levels of pollutants allowed in the atmosphere were singled out as being too high and therefore changes in ambient air quality standards were recommended. The role of the Energy Resources Conservation Board was questioned in several briefs and it was suggested that the Board be funded entirely by government. Some concern was expressed in two briefs about the total amount of sulphur dioxide being allowed into the atmosphere over Alberta as at present there do not exist regulations which limit this quantity. Monitoring practices by government and industry were also called into question and it was felt that monitoring systems were at present inadequate. One recommendation put forward was to monitor for additional compounds other than sulphur dioxide and hydrogen sulphide.

2.7.3 The Industry Viewpoint

Over half of the industry submissions and the Canadian Petroleum Association brief discussed regulatory agencies and regulations. The two main points brought out by the industry were that present ambient air quality standards are stringent enough and industrial emissions should be controlled only by the ambient air quality standard; that is, there should be no control on the actual emissions at the stack. Industry based its position on the fact that ambient air quality standards have been set to protect the

environment and there is no scientific evidence to show that the environment has suffered from these contaminant levels. The Canadian Petroleum Association stated that the present levels are set too low, as research has shown vegetation can sustain higher concentrations. Also stated in this brief was an indication that more stringent standards will not affect the odour problem since the present standards are below the odour threshold for sulphur dioxide. With regard to new regulations issued in 1971 by the Energy Resources Conservation Board, which will require an increase in sulphur recovery efficiency, the industry felt that these regulations were in opposition to environmental protection. The reasoning for this was that it would require considerable expense and energy to recover a small quantity of a material which had not caused any environmental damage. With few exceptions gas plants were applying for exemption from the regulations (increased recovery efficiencies and tail gas clean-up will be discussed more thoroughly in Section 2.7.6).

The industry stated at the hearings that it was somewhat confused about the roles of the Department of the Environment and the Energy Resources Conservation Board. Although the Department sets the standards and the Board devises the means and regulations to meet these standards, in some instances the Board has set its own stricter standards. Industry therefore requested the Department of the Environment and the Board to re-examine their roles and to prevent any duplication.

Other recommendations put forward by the industry were:

1) allow the operator of each individual plant to determine the sulphur recovery efficiencies which will meet the ambient air quality standards;
2) Energy Resources Conservation Board Regulations concerning tail gas clean-up should be more flexible and suited to individual plants;
3) industry and the Department of the Environment should cooperate on research and establish regulations based on the results of this research.

2.7.4 Monitoring Practices

The various operations involved in the processing of a sour natural gas and the attendant effluents resulting from these operations are monitored in various ways. Many gas plants control their operations by using continuous gas chromatographic analysis of the various streams within the plant; however, the monitoring techniques required on their effluent streams are specified by the Department of the Environment or the Energy Resources Conservation Board. Continuous stack emission monitoring is required by all gas plants which produce over one hundred tons of sulphur per day. A network of exposure cylinders which give a cumulative reading of the total sulphation and hydrogen sulphide in the atmosphere must be set up around all gas plants. Also required are dust fall cylinders which also provide a cumulative record of the amount of sulphur dust falling in a given area. The Situation Report expressed concern for two things: one, that exposure cylinder data are not presented in a form which is related to the units in which current ambient air quality standards are given, and two, the ability of the cylinders to function properly at extreme winter temperatures has yet to be determined. The larger sulphur extraction gas plants have been required to have at least one mobile air monitoring trailer situated near the plant. These trailers monitor, on a continuous basis, hydrogen sulphide and sulphur dioxide concentration, wind speed and wind direction. Most of these mobile trailers are checked daily by plant personnel; however, representatives from one plant indicated at the hearings that several of their trailers contained telemetering facilities which instantaneously relayed readings back to the plant. In this case plant operations were often based on these readings.

Liquid effluents are also governed by certain regulations. For example, any plant which recovers in excess of 100 barrels per month of produced water is required to re-inject this water into an underground formation. Process waste water, that is water utilized in the various plant operations, must meet certain minimum levels for biological oxygen demand, threshold odour number, and various chemicals before it is released into any receiving body of water. Most often the various chemicals

and water streams used in plant operations are sent to holding ponds where they may be treated in one way or another before being released to a water course. All activities which require monitoring, in both the liquid and gaseous effluents, must be reported to the Energy Resources Conservation Board and the Department of the Environment on a monthly basis.

Several industry representatives mentioned at the hearings that they have various monitoring practices which are not required by regulation. As part of one research program, plume monitoring was carried out to determine plume characteristics and concentration of contaminants within the plume. A number of gas plants have set up atmospheric corrosion stations to compare corrosion found near the plant with that found in other areas of the Province. One plant mentioned that it had a fish bioassay monitoring program in which it tested various chemicals for toxicity to fish before the chemicals were used in plant operations; the plant also maintained an aquarium in which the fish lived in water effluent before it was discharged into a creek. Both the atmospheric corrosion and the fish bioassay could be considered as continuous monitoring systems, whereas the plume monitoring and other techniques, such as "false color" infrared photography, to study vegetational stress and soil sampling could be considered as intermittent monitoring.

2.7.5 Dispersal of Air Pollutants

In the first section of this summary the effects of atmospheric emissions on the environment were discussed but the means whereby these emissions are dispersed was not mentioned. This section will therefore look at the latter aspect.

In discussing atmospheric emissions it must be remembered that while the incinerator stack is the main source of plant emissions there are also flare stacks which disperse contaminants. For the approximately twenty-five sulphur extraction gas plants in the province which do not recover elemental sulphur, these flare stacks are the only dispersal point for their emissions. In the incinerator stack, combustion takes place at the base of this stack with the gases being vented to the atmosphere at the top at a high velocity and temperature. At the flare stack, on the other hand, gases are combusted in an open flame at the tip of the stack and dispersal occurs at this point. The Situation Report expressed concern about the possibility of incomplete combustion occurring at the tip of flare stacks and it recommended that further research be carried out to look into the combustion processes and the calculations used in flare stack design.

Air chemistry of sulphur dioxide was briefly discussed in the Situation Report. Under normal atmospheric conditions, sulphur dioxide can be oxidized to sulphuric acid or a sulphate salt; dust particles in the atmosphere probably act as sites for the reaction mechanism. The scouring effect of rainstorms on atmospheric emissions was also mentioned at the hearings. In two independent studies, covering an area of central Alberta, it was found that between twenty and sixty percent of the emissions from a gas plant may be removed in precipitation during a rain storm. Deposition in this manner can occur in relative proximity to a gas plant and it has been estimated that from two to four pounds of sulphur per acre comes down in precipitation in central Alberta.

Stack design and equations used to predict ground level concentrations of pollutants came under discussion by the Canadian Petroleum

Association. It was the contention of the Association that present methods are more than adequate for environmental protection as the ambient air quality standards are met at least ninety-nine percent of the time. The Association did indicate, however, that more detailed calculations should be used for unique topographical and meteorological conditions.

Plume integrity, that is the behaviour of the plume from the time it leaves the stack until it is completely dispersed in the atmosphere, was also discussed in the Canadian Petroleum Association brief, by the Association's consultants and by a meteorologist. The industry was of the opinion that under normal circumstances the plume is dispersed quite rapidly and the concentration of contaminants within the plume also decreased rapidly. While the concentration of sulphur dioxide at the stack mouth may be approximately 10,000 ppm, dilution factors of 5,000 to 10,000 occur within the plume in a relatively short time. Helicopter and airplane surveys taken within plumes have found a maximum concentration of only 1 ppm. Industry spokesmen agreed that plumes can hit the ground but it was their contention that concentrations of contaminants would not be high enough to cause any damage. However, one private individual who lives near a gas plant recalled an incident fourteen years ago when he was overcome by a plume.

The only meteorologist making a submission to the hearings expressed concern about atmospheric dispersal of pollutants and the effects of gas plant emissions on the weather. It was noted that the present mathematical models are suitable only for neutral or unstable atmospheric conditions and are valid for a distance of from five to ten miles downwind; in Alberta these conditions occur only a fraction of the time. There is also a special problem of chinooks, to which little attention has been directed. As indicated in the same brief, gas plant emissions may be modifying the weather. It was noted that within the last ten to fifteen years over central Alberta there has been a noticeable decrease in hail damage with a concurrent increase in the frequency

of soft hail. Gas plant emissions have also increased considerably during this period of time. Whether or not there is a relationship between these two phenomena has yet to be proved. It was recommended in the brief that more extensive research into the fate of emissions is required. Similar concerns and recommendations were also expressed in the submission from the Canada Department of the Environment.

With the exception of the two above-mentioned briefs, individuals and associations did not direct specific attention to atmospheric dispersal. The possibility of topographical or meteorological conditions producing high concentrations of pollutants was mentioned in a few briefs.

2.7.6 Tail Gas Clean-up

In 1971 the Energy Resources Conservation Board issued new guidelines which were designed to decrease the total emissions of sulphur dioxide into the atmosphere. The guidelines stated that, by the end of 1974, each gas plant would have to attain a certain recovery efficiency within a range of from 90-99%, the efficiency depending upon the size of the plant. During the hearings industry opposed the implementation of these guidelines as it was felt that they could not be justified on either environmental or economic grounds. Industry stated that there is a lack of proof of environmental damage at current emission levels and that the value of sulphur recovered would be far less than equipment and operating costs necessary to achieve the increased recovery.

About half of the individual plant submissions and the Canadian Petroleum Association brief discussed tail gas clean-up. Although it was noted that two new sulphur extraction gas plants have installed tail gas clean-upsystems, many individual plants were asking for exemptions from the guidelines. One company did, however, state that it would install equipment for increasing the recovery efficiency, while two of the companies stated that they should be able to meet the guidelines without addition of new equipment.

In tail gas clean-up an additional hydrogen sulphide and sulphur dioxide recovery system is placed between the Claus sulphur recovery unit and the incinerator. As normal Claus unit operations can recover a maximum of ninety-six to ninety-seven percent of the hydrogen sulphide, then the tail gas clean-up will be necessary in larger plants (which will have to recover 98-99%) if the new guidelines are to be met. The Situation Report indicated that there are about fifty known processes for sulphur dioxide and hydrogen sulphide removal from gases; however, only a few of these may be applicable to sour gas plant conditions. Two of these processes are in current use in Alberta and a representative of a company manufacturing one of these presented a submission describing their process and the economics involved.

2.8 SOLID AND LIQUID EFFLUENTS

2.8.1 Sulphur Dust

Sour gas plants in the province have had to contend with a problem of sulphur dust blowing downwind from the plant site. The dust results from crushing of the storage blocks and loading of the crushed sulphur into railway cars. With the introduction of a slating process in which the liquid sulphur is solidified into small slates, thereby eliminating a crushing step, the dust problem will be greatly reduced. It was noted in the Situation Report that an estimated 100 to 300 acres in the immediate vicinity of the gas plants have been sterilized as a result of sulphur deposition. Several companies discussed soil sterilization at their plant locations and indicated they were in the process of reclaiming the areas through the addition of lime to neutralize the sulphur; one company stated the sulphur dust was actually beneficial in lowering the pH of an acidic soil near the plant. In one case test plots of various crop plants have been grown to determine the productivity of reclaimed soil.

Sulphur dust being deposited on private land was mentioned by four individuals; however, three of them stated it appeared occasionally after rainstorms. The official reply to the enquiries of the latter three had been that the yellow dust was actually a pollen. Sulphur from freight cars passing through one town was causing concern to the town. The UNIFARM submission cited the results of their questionnaire in which evidence of sulphur dust on an individual's property was indicated in twelve replies while thirty-five stated there was no evidence; five replies indicated sulphur had been found in streams and water pools, whereas twenty-six had not noticed it.

2.8.2 Waste Liquid Effluents

This subject was not discussed in any great detail at the hearings. Only seven of the industry briefs mentioned their methods of liquid disposal; all of these companies, with the exception of one, indicated that both processed and produced water was injected into an underground formation. One company outlined the treating procedure used to purify up to half a million gallons of water per day before release into a nearby creek. Only two non-industry briefs mentioned effects of liquid effluents, one to state the specific case of an oil spill from a heater house and the other to mention the existence of a study that had been done on fish kill in the Drywood Creek.

The Situation Report provided additional information concerning liquid effluents. The Department of the Environment, rather than the Energy Resources Conservation Board, has jurisdiction over this aspect of operations. Two types of water result from plant operations; formation water which is produced with the sour gas and if over 100 barrels per month must be re-injected into an underground formation, and the process water which is required at various stages throughout the operation.

When these wastes are not injected, they are generally sent to settling ponds and in some cases where toxic combustible effluents are present a stream of this effluent is sent to a pit where the compounds are burned in an open flame.

Surface water run-off can also be considered a liquid effluent. Two plants indicated that the surface run-off from the plant site was routed into holding ponds where it was treated before being released to a water course.

2.9 RESEARCH

Throughout the hearings industry representatives outlined various research projects in which they were engaged or had under contract. The results and interpretation of them have been discussed where necessary in previous sections and attention in this section will be directed to the actual research activities. These research activities can be classified in three broad categories; that is, research into environmental effects off the plant site, in-plant research and what may be called other research, such as the uses for sulphur. Although only two non-industry briefs mentioned research that was being carried out, several of the briefs made recommendations for research and these will also be mentioned in this section.

2.9.1 Research: Off-Plant

Much of this research was mentioned earlier in the summary and some of the programs were: corrosion stations, effects of emissions on vegetation, effects of sulphur dust on soils, soil sampling, plume studies and precipitation studies. Three of these are discussed in this section. In addition to these studies, it was noted at the hearings that the Canadian Forestry Service has been assessing the impact of sulphur dioxide on vegetation near two new gas plants. Results of these latter studies were

not presented at the hearings. It should also be mentioned that the slating process, used to cut down on sulphur dust, was developed in Alberta.

Several companies have contracted with consultants to determine the effects of emissions on vegetation and a favored technique used in these research studies is that of false color infrared photography. This is a remote sensing method in which an aircraft flies over an area under inspection and records the infrared emissions from vegetation on a special film. The false color film has a pronounced sensitivity in the yellow, orange, and red wave lengths,unlike a normal film. As the energy emitted by vegetation depends on the state of its health, this technique can be used to survey large areas and detect damaged vegetation. As was noted by the consultants, the state of the art for this technique is such that actual visual inspection of the vegetation should be made in conjuntion with the photography before damage is attributed to pollution.

Plume studies were mentioned earlier in Section 6 and these can be carried out in two ways. One consultant discussed the use of correlation spectroscopy, whereby the concentration of pollutants in a plume is measured by passing a beam of light through them. In order to do this, it is necessary to fly an aircraft directly in the plume path. Another method that was mentioned at the hearings was to fly a helicopter in a plume and directly obtain air samples. Equipment on board the helicopter can then actually measure the various contaminants. In the study discussed at the hearings, only sulphur dioxide was measured in the plume, and the maximum concentration found was 1 ppm.

Two briefs presented at the hearings mentioned that two independent researchers had looked at sulphur in precipitation over central Alberta during the past few years. The method involved was to gather samples of rain from storms and to determine the sulphide content of the rain water. The results of one of the studies indicated that up to fifty percent of sulphur dioxide emissions from a gas plant may come down within a twenty-five mile radius of the plant during a storm.

Industry was of the opinion, as noted in the Canadian Petroleum Association brief, that this deposition was beneficial to agriculture. With regard to weather modification one of the above researchers has been involved in a program to do a detailed study relating plant emissions to the frequency of soft hail that has been found over central Alberta in the past several years. The concern here was that this weather modification may become more intense as the gas plant emissions increase.

2.9.2 Research: In-Plant

The Canadian Petroleum Association brief and the Association representative discussed research on three plant stages: the front-end reaction furnace, the Claus unit, and tail gas treating section. Much of this research is being done by the Alberta Sulphur Research Institute, an organization funded by the industry. The research is aimed at increasing sulphur recovery efficiencies and the Institute is looking at new materials, catalysts, and equipment designs. As noted in the C.P.A. brief the main problem working against an increased recovery is the dilution of hydrogen sulphide and sulphur dioxide as it passes through the plant. Another problem mentioned was that of contaminants such as carbonyl sulphide and carbon disulphide, generated in the reaction chambers and not removed by most tail gas clean-up units. With respect to these contaminants, one spokesman noted that an improved cleanup unit, similar to one already in service in Alberta, will recover these contaminants; the Alberta Sulphur Research Institute has also recently invented a process which will recover these contaminants.

With the exception of one company, which named several of its research projects such as waste water incineration, hydrogen sulphide removal from liquid sulphur, and sludge treatment of waste chemicals, none of the industry briefs discussed other in-plant research.

2.9.3 General Research

A major problem facing the industry will be the disposal of all sulphur being stockpiled, the amount of which is expected to be approximately 25,000,000 tons by 1976. The Alberta Sulphur Research Institute has been looking at various uses of sulphur and has indicated that the only market which would move vast quantities would be in some segment of the construction industry. The Institute has been looking at building materials such as for houses or paving blocks and has had some promising results. One problem that must be overcome, however, is to prevent the sulphur from exploding at low temperatures, especially those experienced in the Canadian winter.

2.9.4 Recommendations for Research

General recommendations were made in numerous briefs presented at the hearings and will not be mentioned in this section as they have been noted throughout the summary. As an example of one general recommendation, many individual submissions contained requests for further investigation of emission effects. Several briefs recommended more extensive off-site monitoring, although the industry stand on this was that present monitoring facilities were sufficient. Monitoring for additional contaminants other than hydrogen sulphide and sulphur dioxide was called for in four briefs while two briefs requested a field survey of area residents in the vicinity of gas plants. Other recommendations for research mentioned during the hearings were more soil sampling and analysis, research on sulphur and selenium metabolism, a cost-benefit analysis relating pollution equipment and property damage, analysis of meteorological conditions, the setting up of a network of precipitation sampling stations, the development of dispersion equations suitable for Alberta conditions, the use of lichens to monitor air pollution, and a study to place natural gas processing in perspective with other pollution sources.

Who should pay for research: only three briefs addressed this question and the answers they gave were government, industry, and a sharing arrangement between government and industry.

2.10 ECONOMICS

During the hearings the Canadian Petroleum Association and individual industry representatives discussed economic benefits and operational costs of gas processing plants. On the economic benefits side it was pointed out that over $800,000,000 can be attributed to investment by the natural gas industry in Alberta. This industry employs over 5,000 personnel and has a high job multiplier effect; figures also show that approximately 15% of personal income in Alberta derived is from the gas industry. Two economic factors adversely affecting the industry at present are sulphur prices and the cost of pollution abatement equipment. It was noted that market demand for sulphur is approximately fifty percent of total production and as a consequence sulphur stockpiles will continue to climb until the amount in storage may reach 25,000,000 tons by 1976. Moreover, the market value for sulphur in 1972 was about $7, compared to $35 in 1968. Due to the low current price of sulphur, industry is now considering it as valueless when calculating its return on plant investment economics.

Opposition to increased sulphur recovery was based on the uneconomic nature of the operation. An example given by one company of the economics involved in meeting the new recovery guidelines was that expected revenue from additional sulphur recovered might be approximately $66,000 per year whereas operating costs to attain this recovery would be $566,000 per year. The cost of the energy expended alone would be greater than the sales value. As this particular company pointed out, even on an environmental basis the operation is not sound.

Various estimates of the cost for pollution abatement equipment were given at the hearings. In a brief submitted on behalf of a company

selling tail gas clean-up equipment the estimate for the entire industry in Alberta was approximately $20,000,000. The Situation Report quoted an estimate of $34,000,000 whereas the Canadian Petroleum Association believed the figures to be between $30-40,000,000. Only two individual plant operators stated costs; for one large plant this would be $15,000,000 and for another intermediate size plant it would be $4,000,000.

2.11 RELATED TOPICS

2.11.1 Oil Sands

The terms of reference for the public hearings did not include oil refineries or extraction plants operating on oil sands although both are sources of sulphur dioxide emissions. Recognizing that future development of the oil sands can increase the danger of environmental degradation in that area, several briefs expressed concern and recommended that further research into environmental matters be undertaken. In fact, the Canada Department of the Environment recommended that a meteorological tower be established on the oil sands. The Great Canadian Oil Sands Limited representative appeared at the hearings and outlined the position of their company with respect to environmental matters. It was pointed out that their operation was somewhat different from that of sour gas plants in that the bitumen contains 4.5% sulphur and that there may also be a potential hazard from ammonia used in the operations. The brief stated that no environmental damage has occurred as a result of plant operations; however, future plants in the area may create problems.

2.11.2 Situation Report

The Situation Report was commended by the industry and reprimanded by a few associations and individuals. The Canadian Petroleum Association and several industry spokesmen felt that the report had successfully outlined the situation in Alberta concerning sulphur extraction gas plants.

On the other hand, three briefs indicated the report lacked information on the impact on health, wildlife and livestock, and it did not discuss social or biological costs or cost-benefit analyses; nor did it include recommendations. Two possible explanations for these suggested shortcomings were advanced; that is, the report was prepared by a single consultant or the information that was not included was in fact not available.

2.12 POST-HEARING CRITIQUES AND EPILOGUE

Following the hearings and before the report and recommendations were completed, the Environment Conservation Authority received an analysis of the hearings from two sources, the Canadian Forestry Service and the Science Advisory Committee. The latter group is a scientific advisory body to the Environment Conservation Authority. The Canadian Petroleum Association submitted a brief epilogue of its reaction to the hearings.

2.12.1 Canadian Forestry Service

The comments of the C.F.S. were directed to a section of the Canadian Petroleum Association brief that discussed pollution effects on vegetation. The C.F.S. was critical of this industry brief in using studies which presented an extremely attenuated picture regarding vegetational life sensitivity ratings. It was also stated that the brief directed its attention to higher plant species and disregarded the lower plants which are much more sensitive to sulphur dioxide. Also, the sulphur dioxide limits suggested by the C.P.A. and the extrapolation of data to Alberta conditions were both seriously questioned.

The Canadian Forestry Service also submitted a literature review on the effects of sulphur dioxide on forests. A final statement of the review noted that present ambient air quality standards permitted during flaring, that is, 1 ppm sulphur dioxide for less than an hour, will potentially result in injury to Alberta forest species.

2.12.2 Science Advisory Committee

In its analysis, the committee chose to concentrate on the Klemm Report and the C.P.A. brief in particular, on industry briefs in general, and to make some overall observations of what the hearings did or did not achieve. With regard to the Klemm Report, it was pointed out that topics covered were only given a superficial treatment while at the same time some important areas were entirely neglected. As a result of the shortcomings in this report the committee recommended that such a project should be undertaken by a group of consultants and not a single individual.

The C.P.A. brief was noted as tending to over-emphasize public benefits and under-emphasize public disbenefits, a defensive position that was to expected by the industry. In this context the committee felt that this brief presented a biased opinion on many matters, in some cases not considering certain aspects of a situation or omitting relevant information.

It was also noted by the committee that there were essentially two opposing groups appearing at the hearings, each of which made charges that were essentially countered by the other. As a result the situation with respect to sour gas plants was not really clarified, but areas for further investigation were determined. Some of the necessary studies were considered to be: biological monitoring of plant effluents, detailed material balances of gas plants, investigations of short and long-term effects of emissions, and an investigation of monitoring practices. In addition it was recommended that the discipline of resource or environmental economics was of vital importance to an understanding of externalities of gas plant operations and should be considered when examining the industry.

2.12.3 Canadian Petroleum Association Epilogue

The Association reiterated its stand on the separation of the Department of the Environment and Energy Resources Conservation Board roles,

that only ambient air quality standards should control emissions, and that industry was willing to discuss the setting of standards with government. In addition, the epilogue stated that there should have been government input other than the Klemm Report at the hearings, that research mentioned during the hearings was only a part of the total effort of the industry, and that the intensity or sophistication of any particular monitoring program should only be based on the need to meet such uncertainties as may be uniquely observed. Furthermore, the role of the Energy Resources Conservation Board in setting sulphur recovery efficiencies was questioned in that non-energy mineral resource recovery efficiencies are not normally specified by government regulations.

3. LISTING of RECOMMENDATIONS OBSERVATIONS and CONCERNS

Briefs presented at the public hearings contained many points which indicate the scope of environmental effects of sulphur extraction gas plants. To outline the main points, a tabulation has been made of those mentioned in three or more briefs. The various parties making the submissions have been indicated as Industry (I), individuals (P), associations and groups (A), governmental bodies (G). Briefs presented were: I-17; P-21; A-16; G-7. It should be noted that the comprehensive submission by the C.P.A. on behalf of the industry is included with (1) in the present tabulation.

3.1 INDICATED IN THREE OR MORE BRIEFS

3.1.1 Recommendations

	I	P	A	G
present standards are adequate........................	8			
revise tolerence levels; set more stringent standards..		6	3	2
control emissions by ambient air quality standards..	9			
more extensive monitoring; include other pollutants...		2	2	
use biological indicators (i.e., lichens) for pollution detection.............................		1	2	1
oppose tail gas clean-up as present standards adequate................................	5			
clarify roles of DoE and ERCB.........................	5	1		
require more research into environmental effects......	1	4	4	2
industry, government and people co-operate on research projects..............................	6	1		
companies must prove no enviromental damage has or will be done................................		2	1	

3.1.2 Observations on Environmental Effects

	I	P	A	G
little or no environmental damage has occurred........	6	1	1	2
yes, general environmental damage has occurred........		1	3	1
human health has been affected......................		14	1	1
no evidence of damage to health......................	3			
physician believes health problems due to air pollution..................................		3		
livestock health has been affected..................		12	2	1
evidence of damage to vegetation (the industry agrees there has been slight damage)................	8	8	3	2
physical damage (corrosion, rust, paint).............		12	2	3
odour is noticed.....................................		10	4	2
water pollution has occurred (one industry brief said there has been none)......................		1	1	1
situation has improved (one person said it was worse)..		5		1
sulphur dust on property............................	3	2		
believe yellow in rain puddles was S dust, officially told it was pollen.......................		3		1
no problem before plants built....		3		
smoke evident..		4		
sulphur is beneficial to soil........................	2		1	
the company accepts its corporate responsibility......	4			
good plant-community relationships...................	3	1		2
conducting research into biological effects (on vegetation).......................................	6			
research into weathering, rusting, etc...............	3			
reclaiming soil......................................	3			
few or no complaints.................................	4	1		2
operations beneficial (roads, employment, etc)........	4		1	
design equations are conservative....................	3			

3.1.3 Concerns

	I	P	A	G
pollution control is not economical (refers mainly to tail gas clean-up)........................	6			
legal recourse is inadequate.........................		7	1	
lack of government co-operation.....................		3	2	1
credibility of government is questioned..............		1	1	1
atmospheric conditions may hinder monitoring and control..............................		1	1	1
sulphur plants contribute to selenium deficiency......		3		
industry doesn't co-operate with people..............		3		

3.2 INDICATED IN ONE OR TWO BRIEFS

3.2.1 Recommendations

Present standards are too low (I); sample pollutants at point of discharge (P,G); set standards by lack of environmental damage (I); allow guidelines to apply to plants on an individual basis (I); regulating agencies should take stronger disciplinary action (P,A); do more research on emission equations (I); government sponsor research (I); companies responsible for research (A); research by independent agents (P); make research results available to public (I); let public know what is happening (I); more soil sampling (P); improve S transportation method to prevent dust (G); involve workers in environmental matters (A); protect workers legally from reprisal in reporting (A); upgrade training; enforcement, inspections (A); safety record good (I), not good (A); be concerned about tar sands (P,A).

3.2.2 Observations on Environmental Effects

Animal health has not been affected (I); no evidence of physical damage (paint deterioration, etc.) (I); workers have been affected by H_2S, noise, (A); considerable flaring (P); little flaring (I); property value in vicinity of plants has decreased (P,G); property value has increased (I); plant sites are visual pollutors (P,A); individuals have complained to plants (P); no research has been done on the effects of gas plants on people (P); not certain of pollutants (P); co-operate with other plants (I), (indirectly plants co-operate through the Whitecourt Environmental Study Group and the Alberta Sulphur Research Limited); plant does not consult with the community (I,G); research is being done on plant process (I); plant is not doing any research (I); plant tests chemicals with a fish bioassay (I); have applied for exemption from guidelines (I); can meet guidelines without tail gas clean-up(I); will install tail gas clean-up(I); plant answers complaints (I); flaring is necessary (I); workers are (are not) involved in environmental protection (I[1]); safety meetings are held between workers and administration (I); little evidence workers affected by threshold limit value for gases (G); design equations are acceptable (CPA)(I), not acceptable in the location of a particular plant (I); plant exceeds standards on occasion (I).

3.2.3 Concerns

Ambient standards vary across Canada (I); increased S recovery not an environmentally sound practice (I); worker safety and lack of safety training (A); tolerence levels uncertain (I); monitoring not sensitive enough (I,P); cost to the individual in proving damage (P); regulations not adequately enforced (P); people have become sensitized to pollutants (P); problems occur with plant upsets (P); value system not just (P,A); plant has a problem relating complaints to plant records (I); government testing program can be questioned (A); experts don't see

problems (P); long-term effects of S on soil (P,A); government interference with Klemm Report (P,A); the report was not written by an interdiciplinary committee (P,A).

4. SELENIUM, ANIMAL HEALTH and SOUR GAS PLANTS

A submission regarding an indirect effect on sulphur emissions was heard at the hearings. It had to do with the occurrence of selenium deficiency diseases in domestic animals.

In western Alberta, particularly in the environs of the Sulphur Extraction Gas Plants from Pincher Creek to as far north as Whitecourt, there has been a relatively high incidence of selenium deficiency diseases in domestic animals. Selenium is essential as a nutrient for animals and a lack of a proper supply can lead to severe debilitation of the animal. Many farmers and some veterinarians in western Alberta attribute the rise in the incidence of White Muscle Disease to emissions from sour gas plants.

It is known that elements which are similar to each other can replace each other in chemical reactions both within and outside of living systems. The element most similar to sulphur is selenium. In view of this the Authority commissioned a staff report on the suggested relationship of selenium deficiency diseases to ambient sulphur concentrations in the area. The report appears in full in the present chapter. Information relevant to the problem is also to be found in two reports from the Canadian Forestry Service on the effects of sulphur dioxide on vegetation, which appear as Appendices 2 and 2A.

4.1 SELENIUM IN SOILS

Selenium is a naturally occurring trace element in soils. Its concentration in the various soil types is intimately associated with the original geologic formation and its subsequent history to the present. (Figure 1 outlines the boundaries of the soil zones in Alberta.) Not only is the selenium content variable among these soil zones but also the chemical form in which it is held. Thus, it is quite possible for a soil to contain a large amount of selenium yet in a form which does not permit its incorporation into the plant tissue. This is a rather general feature of soils and may be extended to all plant nutrients. For example, a particular soil may be high in sulphate sulphur and yet be considered deficient in the sense that such sulphur may be as water-insoluble calcium sulphate, magnesium or aluminum sulphate and thus unavailable to vegetation. Analytical techniques are known which can determine the amount of soluble sulphate in the soil(Carson et al., 1972). Unlike sulphur, unfortunately, there is no analytical method presently available by which soluble selenium content of soils may be determined as all techniques determine the total selenium content. Therefore, when one speaks of selenium-deficient soils, the phrase implies that the above-ground portion of crops grown on such soils contains concentrations of selenium insufficient to meet the nutritional requirements of animals or humans dependent upon that crop as their sole food supply. A comparable definition may be extended to soils having toxic levels of selenium.

4.2 SELENIUM IN VEGETATION

Crop plants in which we are interested do not seem to require selenium as an essential growth element; in this report the plant acts as a carrier for selenium, transmitting it to the animal. Certain plant species

do require selenium as an essential nutrient, but they are not believed to exist in Alberta. There are plants, however, which take up much more selenium than the others, these have been termed "selenium accumulators". A certain milk vetch species (Astragalus sp.) grows in Alberta and may contain a selenium level so high as to be toxic to livestock. This plant is usually consumed only if an area has been over-grazed or there is no other food available. While there have been cases of selenium toxicity in livestock in the Manyberries area of southern Alberta, they have been few in number.

Selenium incorporated into a plant enters via the root system as a soluble selenite or selenate. While the selenium is not required as a nutrient in forage crops, nevertheless it is chemically incorporated into the plant proteins. Associated with the proteins, it is apparently present mainly as seleno-amino acids: selenocystine, selenocysteine, selenomethionine, and selenocystathionine. There also is a fraction of the total uptake which remains as selenite or selenate.

Two studies of selenium levels in Alberta forage exist. D.R. Walker, Canada Department of Agriculture, Lacombe, has been measuring forage response to sulphur fertilization for a number of years. Recently this work has been expanded to include plant selenium measurements (Walker, 1971a). D.L. Massey and P.J. Martin, Alberta Department of Agriculture, have classified the soils of Alberta on the basis of selenium concentration measurements obtained from barley grains grown in the various Alberta soil zones (Massey, Martin, 1972a).

Walker (1971a) measured the selenium content of 262 samples of alfalfa, red clover, alsike clover, timothy and bromegrass grown at 59 soil-year sites. The data from this study are given in Table 1. Forty of the soils were classified as sulphur deficient, as determined by legume yield response to fertilization. Selenium levels in the above species were decreased by a statistically significant amount only where fertilization had increased plant yield. This Walker attributes to "dilution", or a relatively constant selenium uptake as forage yield increased. It is evident from this study that alfalfa takes up more selenium than other

species and that practically all of the samples had selenium levels that would be considered as deficient for animal nutrition, if it is accepted that between 30-200 parts per billion of selenium in a diet is essential to animal vitality (Massey, Martin, 1972b). Any level below 100 parts per billion is considered by animal nutritionists to be potentially deficient.

In 1972 Massey (Massey, Martin, 1972a) analyzed 394 samples of barley grain from all areas of Alberta. The grain had been submitted by farmers for routine testing during the period 1970-72. There was obviously less control of sample history than in the study by Walker. The data for this study are given in Table 2 and the corresponding source soil areas are indicated in Figure 1. It should be noted that throughout the Province there are found areas where forage will contain less than an average of 100 parts per billion selenium, but that the most prominent selenium-deficient area is the northern two-thirds and west central part of the Province. In these areas over one-half of the samples tested contained less than 100 parts per billion selenium.

The areas outlined in Figure 1 delineate the soil zones of the Province. These soils vary in their organic matter and those elements essential to plant growth. Consequently the availability of selenium is also expected to be a function of soil type. As an example, Grey Wooded soil, zone 8, is extensively leached and usually deficient in nitrogen, phosphorus, organic matter, and often sulphur. It is within this zone, particularly west of Highway 2, between Edmonton and Calgary, that selenium/vitamin E responsive diseases have been most often observed. Although the scope of this study (Massey, 1972) is limited to one grain type, there would certainly appear to be a correlation between selenium level in the forage and the type of soil. On the basis of the data there obviously appear to be many areas of the province where selenium deficiency can create a nutritional problem.

Apparently there are two ways in which selenium uptake by a plant can be depressed when sulphur fertilizer is added to the soil. Walker (1971a) attributed the decrease in selenium concentration mainly to "dilution", that is, a relatively constant selenium uptake as forage yield

increased. This dilution effect has also been reported elsewhere (Davies and Watkinson, 1966) to be the principal factor which decreases the selenium concentration. A direct inhibitory effect of sulphate ions replacing selenium was also reported by Hurd - Karrer (1938) and Ravikovitch and Margolin (1959). Such an effect is to be expected due to the chemical similarity of the two elements. It has been demonstrated that selenium can replace sulphur in plant amino acid synthesis, for to quote Treshow (1970):

> "Cases have been reported of one element substituting for another. ...selenium can replace sulfur in certain amino acids such as selenomethionine or selenocystine.
>
> Nutrient ion interaction may affect the absorption of elements from the soil, so that a chemically similar ion may be absorbed rather than the essential element. In this way arsenate may interfere with phosphate absorption, selenate with sulfate..."

Such a similar substitution of sulphur for selenium would be expected when sulphur is present in a large excess. The net result of either "dilution" or "direct inhibition", or a combination of both, will be to decrease the selenium concentration.

4.3 SELENIUM FROM SOUR GAS PLANTS

Selenium and sulphur occupy the same family grouping in the periodic table of elements and as such may interchange with each other in compound formation. On this basis, if selenium were present in any quantity during the time hydrogen sulphide was being formed, then the presence of selenium compounds in sour natural gases might be expected. Selenium is not normally analysed for in sour gases, but one special investigation has been carried out recently. In this analysis of stack gases, stockpiled sulphur, surface run-off water and river water at a gas plant near Pincher Creek and one west of Innisfail the selenium levels were found to be just at the limit of detection (2-6 parts per billion). It is not expected that these quantities of selenium are sufficient to be beneficial to selenium-deficient soils or to lead to concentrations in vegetation that would be considered toxic to animals.

4.4 SELENIUM IN ANIMAL NUTRITION

4.4.1 General

The importance of selenium in animal and human nutrition has been appreciated only within the last few years. Human diets are sufficiently varied such that selenium deficiency diseases are a rare occurrence, but the same cannot be stated for livestock. Moreover, selenium deficiency in animals is not confined to Alberta, but has been diagnosed in other parts of Canada, the United States, and at least fourteen other countries. There are numerous diseases attributed to an insufficient level of selenium in an animal's diet and it is common practice to refer to them as selenium responsive.

White Muscle Disease (WMD), Nutritional Muscular Dystrophy (NMD), or Nutritional Myopathy (NM), myopathy meaning any disease of muscles, are terms applied to the afflictions under discussion. The common name, WMD, is given because of a bleaching of affected muscles which may, in extreme cases, lead to a distinct clarification in skeletal muscle. Both skeletal and heart muscles are commonly affected. However, these are only gross manifestations of the disease. Most changes are microscopic and not easily observed. Clinically the condition appears in calves up to three to four months in age and is characterized by stiffness, muscular weakness, and rapid death if the heart muscles are severely affected; stillbirths are common if the parent is not supplied sufficient selenium. It must be noted that while the main interest in Alberta is directed to cattle, similar symptoms occur in swine, horses, chickens, and turkeys. In swine the common disease name is Mulberry Heart Disease.

Selenium is ingested by the animal in any of a number of compounds. As mentioned in section 1.2, forage contains selenocystine, selenocysteine, selenomethionine and selenocystathionine, as well as selenite and selenate. As much as 70% of the selenium in alfalfa may be bound as selenomethionine (Muth, 1967). The selenites or selenates can be reduced by the animal microorganisms to seleno-amino acids and incorporated into proteins.

Selenium not only remains incorporated in the animal system but it is also reduced to the elemental form in the gastrointestinal tract of ruminants (Muth, 1967). An examination of ruminant excretions showed the following: of the total selenium excreted, 40% was in the urine as selenate and selenite, 40% was in the fecal matter as elemental selenium, and 20% was also in the feces as organic selenium.

Although a certain minimum amount of selenium is essential in animal and human nutrition, its metabolic function is uncertain. It has been suggested that selenium possibly acts as a carrier for vitamin E, serves as an antioxidant, is essential in the synthesis or activation of some enzymes involved in decarboxylation, and takes part in the production or activation of lipose (any of a group of enzymes that aid in digestion). MacDonald (1972a) lists some 25 medical conditions in which selenium and vitamin E have been incriminated as causal agents, either individually or paired.

The standard practice by veterinarians in treating WMD is to inject the affected animal with a solution of sodium selenite-vitamin E. Preventative measures are taken by adding the selenite-vitamin E mixture to mineral salt licks.

4.5 SELENIUM-SULPHUR RELATIONSHIP

The effect of sulphur on the selenium content of vegetation is well understood, as noted in Section 1.2 and in a review article by Allaway (1970). The influence of sulphur on selenium in the animal is not that well defined, however, as a survey of the literature has indicated.

Whanger (1970) discussed the interaction between sulphur and selenium in relation to rumen microorganisms, ruminants and nonruminants. Studies have indicated that rumen microorganisms may alter dietary selenium and metabolize it differently than they do sulphur. Notwithstanding this fact, sulphur easily substitutes for selenium in the biological system and is known to interfere with the metabolic functions

of selenium (MacDonald, 1972a1; Sutmoller, 1972b; Whanger, 1970). On the other hand, both Whanger (1970) and Allaway (1970) mention cases where there is little if any inhibitory effect of sulphur.

Whanger makes an important point in relation to the discrepancy of results from several studies where the interaction of sulphate and selenium have been investigated. Apparently the fate of selenium metabolism depends upon the level of sulphur in the diet: in a study on the effect of 0.05, 0.10, 0.15, and 0.20% total sulphur in the diet, the selenium metabolism for the low S (0.05%) was different than for the higher percentages. This level is below that of sulphur usually found in animal forage (0.1-0.2%).

A conclusion stated in Allaway's paper (1970) is that when areas are low in selenium and require fertilization for good crop yield, fertilization should be undertaken and preventative measures should be taken for WMD. This is a recommended procedure for the situation in Alberta, as the workers interviewed agreed that this would be an effective way to control WMD.

4.6 SELENIUM-CANCER

Selenium has been classified as a carcinogen, resulting in its prohibition as a feed additive. As there is considerable controversy on this point, it will be worthwile to describe the situation; more detail may be found in the paper by Frost (1971).

In 1943 the U.S. Food and Drug Administration (USFDA) reported (Nelson et al., 1943) that rats developed cirrhosis when fed chronically toxic levels of potassium ammonium sulfoselenide, the first systemic insecticide. After 18 months, during which time most of the test rats had cirrhosis, some tumors grew out of the cirrhotic livers. In 1958, selenium was banned as a feed additive under the Food Additive Law, the basis being this 1943 report, although a subsequent paper (Fitzhugh et al., 1944) stated that none of the tumors became malignant. It should be noted that it was not until 1957 that selenium was discovered to be

essential to health. A letter sent by Schroeder (1970) to the USFDA stated that he had produced cancerous tumors by feeding 3 parts per million sodium selenate in water to rats.

In contrast to these two studies and a third in Russia, the literature contains a large number of studies which show the salutary nature of selenium and in fact some investigators indicate that selenium can prevent or inhibit carcinogenesis under certain conditions. Toxicity occurs only when selenium intake exceeds excretory capacity, which is at least ten times the requirement for most species tested.

Considerable effort is currently underway to remove the controversy. Both the USFDA and the Canada Department of Agriculture (CDA) are attempting to establish a case for selenium as a feed additive. The proposed level is 0.1 part per million for chickens and swine, 0.2 part per million for turkeys. Needless to say there is insufficient evidence available at present to clear selenium as a feed additive or mineral supplement in salt licks for cattle on other than a prescription basis.

4.7 THE ALBERTA SCENE

Although cases of WMD have been diagnosed in livestock in most parts of Alberta, the potential total incidence of the disease is unknown. The same can be said for Mulberry Heart Disease in swine. Sutmoller (1972) indicated at public hearings that about 5% of his case load consisted of diagnosed cases of WMD and it is understood most farmers in the Innisfail area are using a selenium dietary supplement. Without selenium supplements the livestock industry in central Alberta would be in serious jeopardy.

The Animal Diseases Section of the Laboratory Services Branch, Alberta Department of Agriculture, has been in existence for several years. The section has been set up to diagnose diseases in animals sent to it by veterinarians and farmers; no research is undertaken. As the only source of province-wide information, the section diagnosed 50 cases of WMD in cattle in 1965; in 1971 the number was 118. In 1971 there were 34 reported cases of Mulberry Heart Disease in swine. However,

these cases represent only a fraction of the total, as local veterinarians see and diagnose the vast majority of animals without the necessity of submitting the details of their case load to any on-going province-wide information center. This is an unfortunate oversight.

It should be noted that the distribution in cases of WMD diagnosed by the provincial laboratory follows very closely the variation in selenium levels with soil zone as indicated in Table 2: the highest incidence is in zone 8, a Grey Wooded soil yielding a high percentage of selenium-deficient forage. This is an area of intensive cultivation in contrast to other grey soil regions of Alberta.

There is one question as to the best method of supplying nutritional selenium dosages to livestock, especially because of the varying levels which exist in forage. Certainly for swine and poultry, which usually have commercial feeds as their only source of food, the addition of selenium to the feed should be an adequate preventative measure, provided strict control was exercised over its incorporation into the feeds. For cattle this method may not prove to be satisfactory, as feeds can be prepared on a local level at mills where the personnel are not knowledgeable about nutritional needs; in addition, cattle are let out to pasture to feed on local vegetation. Veterinarians are more familiar with the health aspects of treatment or preventative measures and they would be more capable of supplying the correct quantities of supplement. The preferred mehtod is to supply the selenium as a mineral supplement in salt licks as this allows the dosage to be prepared on an individual basis. If a more extensive forage testing program were set up by the Department of Agriculture, with the results being forwarded to the local veterinarian, then it is expected that occurrences of WMD and related diseases would be greatly reduced.

4.8 SULPHUR IN THE ENVIRONMENT AND ITS RELATION TO EMISSIONS FROM SOUR GAS PROCESSING PLANTS

4.8.1 Historical

The west central portion of Alberta, wherein the greatest concentration of sour gas processing plants is to be found, in predominantly

of two basic soil types: Grey Wooded soil and Black soil. Grey Wooded soils are low in natural fertility and respond to the application of mineral fertilizers, especially sulphur as sulphate, and additions of organic matter. Careful soil management is required to achieve good productivity from such soils. Black soils, in contrast, are generally of high productivity. In the area in question Grey Wooded soils predominate. Such soils additionally constitute over one-half of the currently cultivated plus potentially arable land of the Province. During the last five years, visible symptoms of sulphur deficiency have appeared in Black soil zones as well. This is not surprising in view of the many years of net sulphur removal by crops. Sulphur deficiency is usually associated with soils having good drainage, coarse texture and a relatively low content of organic matter.

As a result of much experimentation with a variety of soil management programs carried out under the guidance of Dr. C.F. Bentley of the University of Alberta Department of Agriculture, substantially increased forage and grain crop yields have been realized from the soils in question, thereby making sulphur-deficient soils of west central Alberta equal in productivity to much of the most fertile land in the Province. As a consequence of increased forage yields livestock have assumed a greater proportion of farm income generated in this area over the past ten years.

Concurrent with these developments, beginning in the early 1960's, increased incidence of White Muscle Disease (WMD) and general unthriftiness in cattle and hogs was diagnosed in many areas of the Province, but principally in the region south of Edmonton, north of Calgary and west of Highway No. 2 to the edge of the cultivated area. The above mentioned debilitations respond favourably to injections of selenium (as sodium selenite) and vitamin E. The importance of selenium deficiency in feeds as one of the factors contributing to some muscle degeneration diseases has been well documented; suggested essential minimum requirements are 30-200 parts per billion total selenium in the daily feed ration.

4.8.2 The Affected Farmer

Many farmers in west central Alberta are presently opposed to further sulphate fertilization on the grounds that where this has been practiced increased incidence of WMD has resulted. It has further been assumed by many farmers in the same area that increasing emissions of sulphur dioxide from sour gas processing plants and their attendant batteries already contribute sufficient sulphur to the soil to preclude the need for further sulphate additions (Sutmoller, 1972). In this way, then, many farmers and a few veterinarians believe there may be a correlation between gas plant emissions and the increased diagnosis of WMD, especially in areas where sour gas plants are located.

The question to consider then is the relationship between the application of sulphur, either applied in known amounts in a fertilizer or deposited from sour gas plant emissions, and a decrease in the selenium content of vegetation. It has been experimentally shown (Davies and Watkinson, 1966; Walker, 1971) that selenium concentration decreases when plant growth is stimulated by sulphate fertilization (see Section 1.2). Although the literature references attribute the selenium concentration decrease principally to dilution, i.e., a relatively constant selenium uptake by the forage, the increased sulphur available to the plant should also inhibit the selenium uptake. This is to be expected from the relative chemical similarity of the two elements and their ease of exchange in chemical processes.

4.9 SULPHUR FROM SOUR GAS PLANT EMISSIONS

4.9.1 Sulphur in Precipitation

Do the emissions from sour gas processing plants (see Figure 1 for locations of these plants) and their ancillary facilities contribute sufficient sulphur to relieve the natural sulphur deficiency of the soils in west central Alberta? From sulphate analyses of both snow and rainfall from 60 sites within a 3,600 square mile area (35 mile radius) of west

central Alberta, Walker (1969) estimated 2-4 lbs. sulphur/acre/year as sulphate is brought down in precipitation. No doubt some of this is lost as a result of surface run-off. A later independent study by Summers and Hitchon (1971) of the entire area between Edmonton and Calgary west of Highway No. 2, substantiates Walker's results and further suggests that during the winter only a small fraction of sulphur dioxide emitted to the atmosphere is brought to earth as sulphate incorporated in snowfall. The ultimate fate of sulphur dioxide emitted during the winter should be an important matter for further study, although the matter is apparently not immediately relevant to the selenium issue.

Taking into account sulphate added to the soil by precipitation Walker concludes (1969, 1971b) from five field test plots that present (1970) levels of sulphur oxides in the atmosphere over west central Alberta would seem to be contributing insufficient sulphur to the soil to eliminate the sulphur deficiency which exists, except where such deficiency is marginal. Farmers operating close to sour gas plants would tend to dispute this conclusion, however.

4.9.2 Absorption of Sulphur Dioxide by Soil and Vegetation

Direct absorption of sulphur dioxide by the soil and by green plant surfaces is also a source of sulphur for vegetation. The most comprehensive study on soil absorption was done in Sweden by Johansson (1959) whose results indicated direct absorption contributed considerably more sulphur dioxide to the exposed soil than did sulphate sulphur in precipitation. It would only be by integrating data from individual mobile monitors that the Swedish results might be applied to Alberta conditions in even a crude manner. However, Walker concluded in his studies that direct soil absorption was not an important source for sulphur. He did not discuss direct gas absorption by the plant.

Sulphur dioxide absorption by the plant itself is a controversial issue in that it may be thought of as a beneficial aid to plant growth on the one hand and as a harmful pollutant on the other. It is not necessary to enter into a discussion of the harmful effects of sulphur

dioxide on vegetation as this is well documented elsewhere. What is important to note is that there exists a threshold level (not necessarily static) above which damage can be observed in the plant; below this threshold level the absorbed sulphur dioxide may be considered as a plant nutrient. In general, crop yields are not affected unless approximately five percent of the leaf area has been destroyed; for alfalfa,leaf destruction can be approximately five percent without decreasing total yeild, even after several fumigations.

When sulphur dioxide is present in the atmosphere below a level which is assumed not to inflict plant damage, it is often considered to be a plant nutrient, as it can be assimilated into the plant by oxidation through sulphur to sulphate. In fact, it has been found (Katz, 1949) that fumigation of alfalfa with sulphur dioxide concentrations below 0.2 ppm caused no harm, and he suggested that concentrations between 0.1 and 0.2 ppm are beneficial especially on plants prone to sulphur deficiency. This is also the belief of the sour gas industry, for as stated in the Canadian Petroleum Association submission to the public hearings regarding overall sulphur deposition "...in the growing season the sulphur emissions from Alberta gas plants are deposited within Alberta and utilized by crop vegetation." We do not know of research carried out in Alberta to prove the benefical effects of sulphur dioxide emissions.

Plants vary in their sensitivity to sulphur dioxide (or any pollutant) and even an individual species will have a variable sensitivity depending on numerous factors; for example a plant is usually most susceptible to damage in its growing stage. Among the most sensitive species are the forage crops, alfalfa and barley; they are followed closely by rye, oats, clover and wheat; the most sensitive forest species are trembling aspen and jack pine. There is evidence from scientific studies in Alberta that trembling aspen in various parts of the province have exhibited mild sulphur dioxide stress but this has not been shown to have seriously affected this species. Although no evidence has been produced to indicate any sulphur dioxide damage to forage and cereal

crops, the fact that they are as sensitive as and maybe more sensitive than the forest species would indicate that these crops may also have been subject to some stress. These stresses are very often not prominent, but may require examination by an expert to detect, and therefore, given all the variables of crop production, may go unnoticed.

Assuming that low levels of sulphur dioxide are present in the atmosphere much of the time in central Alberta, vegetation can be expected to absorb some of this gas. Under normal conditions this sulphur dioxide may be a nutrient, and in this respect will promote plant growth; it is expected that once the plant oxidizes the sulphur dioxide to sulphate it will be equivalent to sulphate applied as fertilizer. Walker's studies do not indicate that the sulphur dioxide in the air contributed to growth (of course, in relation to this, he did not have test plots that were exposed to pure air for comparison purposes).

4.9.3 Hydrogen Sulphide

Hydrogen sulphide may be another source of sulphur, but the gas plant operations in effect reduce its emission into the atmosphere to much less than that of sulphur dioxide. All sour gases from which sulphur is recovered are burnt in a furnace to convert hydrogen sulphide and other sulphur compounds to sulphur dioxide before emission to the atmosphere. There may be small amounts of hydrogen sulphide released from flares, but this is not expected to be detrimental to vegetation. Hydrogen sulphide is less harmful to vegetation than is sulphur dioxide at equivalent levels; under normal circumstances hydrogen sulphide is not expected to contribute to any large extent to beneficial or detrimental effects on vegetation.

4.9.4 Research

The field plots in Walker's investigation were at a distance no closer than about seven miles from the Homeglen-Rimbey sulphur extraction plant. It is unfortunate that test plots were not situated in closer proximity to the gas plant, especially since the information

available indicates that farmers relatively close to the gas plants have been under the impression that atmospheric sulphur being deposited is sufficient for crop growth and in many cases aggravates WMD. There may be merit in testing for total sulphur deposition on plots closer to a plant, based on the following points: a) sulphur in precipitation appears to increase nearer the plant; b) Johansson's data indicate that more sulphur is absorbed from the atmosphere than deposited by precipitation; c) stack calculation equations indicate that maximum concentration of a stack plume near ground level would normally occur between ten and twenty stack heights downwind: for a 400 foot stack this would be about one to two miles. The published data for Alberta relate only to the Homeglen-Rimbey gas plant which exhausts approximately 20 tons of sulphur (as sulphur dioxide) per day; if deposition is dependent on stack emission then more sulphur may be added to the soil near larger plants.

4.10 FERTILIZATION

Since a large portion of soils are normally sulphur deficient, if sulphur were not contributed by emanation from sour gas processing plants, sulphate fertilizer would have to be added by the farmer to obtain maximum crop growth. However, without regular soil analyses by the Department of Agriculture, local inhabitants find it difficult to ascertain what fraction of their total sulphur requirement has been met by fallout from local sour gas plants or natural soil sulphur and therefore how much additional fertilizer must be applied. Certainly at this time the value of increased crops to be derived from adequate applications of sulphur outweighs the present cost of preventing the occurrence of WMD by adding selenium to salt licks. Even when fertilization is not carried out, there will be a possibility of WMD occurring due to the potential selenium-deficient nature of many soils.

4.11 CONCLUSIONS

4.11.1 White Muscle Disease and its Treatment

There is little doubt that diagnosis of White Muscle Disease has become more frequent over the past few years; incidence of the disease is particularly acute in west central Alberta. Analysis of forage crops for selenium content indicates that there is a geographical variation which closely follows the soil zones. An extensive soil management program primarily based on sulphate sulphur fertilization has converted the Grey Wooded soil of west central Alberta into one of the most productive in the entire province. Such a policy of fertilization has aggravated the natural selenium deficiency by decreasing the already low levels of selenium in vegetation. It should not be inferred that selenium deficiency in animals would not occur without sulphur fertilization.

All evidence indicates that the major cause of the incidence of WMD is the intensive agricultural use of land that is marginal in soluble selenium. More extensive grazing by larger herds and a greater awareness by veterinarians of disease symptoms also contribute to the total reported cases. Fortunately, the diseases discussed in this paper can be controlled, although they cannot be eliminated. The easiest means of prevention, and that recommended by the veterinarians, is to supplement the salt diet of cattle with selenium-vitamin E on a prescription basis; known cases of WMD, etc. can be treated individually with injections. At present the Canada Department of Agriculture is in the process of clearing selenium as a feed additive for swine and poultry and expects to do the same in the future for cattle feed. It would appear that several practising veterinarians are opposed to the addition of selenium to feeds.

4.12 SELENIUM-RESPONSIVE DISEASES, FERTILIZERS AND SOUR GAS PLANTS

While it can be stated that soil characteristics are the predominant factor causing less than nutritional levels of selenium in forage crops, then any growth stimulant may be expected to decrease the

selenium content. It does not matter whether one talks of a "dilution" effect, that is a relatively constant selenium uptake as yield is increased, or as sulphur (from the nutrient additive) substituting for selenium, since the result is a lower selenium concentration in either case. As indicated by Walker's data in Table 1, any livestock fed a diet of this forage other than mostly alfalfa would likely exhibit symptoms of WMD, whether or not the crop had been fertilized. Therefore, it is to be expected that WMD may be evidenced even when farmers do not fertilize their land, especially where the soil is low in soluble selenium.

The location of the majority of sour gas plants in central Alberta appears to be fortuitous in that the Grey Wooded soils in this area are known to be deficient in soluble selenium (from the standpoint of animal nutrition). It could be said that, within limits, sulphur deposited as a result of gas plant emissions is beneficial in stimulating plant growth; however these emissions have been pointed out as the cause of WMD. Many farmers do not fertilize because they believe this increases the incidence of WMD (Sutmoller, 1972; Walker, 1971a) or that gas plants added sulphur to the soil and thereby caused WMD; in fact, it has been stated that two or three years after a gas plant near Innisfail began operation there was an increase in selenium-responsive diseases near the plant. The discrepancy between the experimental data and the beliefs of farmers and veterinarians appears to be related to the distance from the gas plant; unfortunately the only scientific data have been obtained at a minimum distance of seven miles from the nearest gas plant.

In this respect we do not have sufficient evidence to actually state that gas plants have affected crop growth or have been contributory to the increased incidence of White Muscle Disease. All of the following have increased over the past several years: gas plant emissions, use of sulphate fertilizer, marginal land being brought into production, livestock grazing, knowledge of WMD and its diagnosis. The exact role played by each is not fully known and it is doubtful that the necessary information is presently available to determine each role. Judging from what is known, however, we do not believe sour gas plants can be held responsible

for the general increased incidence of WMD. This does not dismiss the possibility that sulphur deposition may in some instances be sufficient as to stimulate vegetation growth, but even in these cases other factors will also contribute to modifying selenium intake.

4.13 ATMOSPHERIC SULPHUR DEPOSITION

From the work of Summers (1971) and Walker (1969, 1971b) the amount of sulphur added to the soil (for the district in west central Alberta near the Homeglen-Rimbey gas plant) in precipitation is estimated to be between 2 and 4 lbs./acre. Walker concludes that the atmospheric sulphur added to the soil is insufficient to affect plant growth, as sulphur fertilization produced significant increases in yield. From an economic point of view it would be beneficial to know the extent of sulphur deposition or soil content so as to prevent this addition of excess fertilizer by the farmer.

The beneficial effect of atmospheric deposition of sulphur to the soil must, however, be viewed in the context of the total environmental situation with respect to gas plant emissions. It must be remembered that from the time sulphur dioxide leaves the plant until it is returned to the soil, it can affect vegetation and the health of humans and animals. At the public hearings, evidence was given to indicate that in certain areas slight vegetational stress due to sulphur dioxide had occurred and several individuals had stated that their health had been impaired by gas plant emissions; unfortunately scientific evidence for the health aspects was lacking. In addition, sulphate deposited and not removed in crop production may lead to soil acidification over a long period of time.

The main conclusion of our report is that the incidence of White Muscle Disease is a direct result of soil characteristics. Gas plants are emitting sulphur which returns to the ground, but unless the total return is much greater than precipitation data would suggest, this sulphur is essentially supplementing the natural soil sulphur and that

applied as fertilizer. If the total atmospheric deposition were known, then in some cases the farmer may obtain sufficient crop yield without adding fertilizer. As long as it is understood that WMD and other selenium-responsive diseases will occur in areas that are marginal in soil selenium, or where the low levels of selenium are affected by sulphur fertilization or sulphur from gas plants, preventative steps for WMD can be taken. Proper farm management will increase the crop yield and prevent the occurrence of WMD.

These statements should not be construed as an endorsation of crop fertilization by atmospheric sulphur sources, as we believe this to be an unsound environmental practice. However, as the gas plants are in existence, and emissions from them cannot be eliminated, then the overall effects of these emissions must be determined, whether they are effects on plants, animals or humans.

4.14 RECOMMENDATIONS

On the basis of our investigation we do not believe that there is a requirement for direct research into selenium-responsive diseases, as extensive work is being done in other countries. It is known that unless preventative measures are taken, WMD and other symptoms of selenium deficiency will occur as a direct result of soil conditions in Alberta. Of utmost importance to the farming community is good crop management and a healthy herd; application of known amounts of fertilizer and supplementing diets with selenium additives (or other necessary nutrients) should ensure this. What is not known is how much sulphur is being added to the soil by gas plants, especially close to the plants, and how this will affect the quantity of fertilizer the farmer must add for maximum crop yield.

The following recommendations are concerned with the present situation regarding relationships among government, veterinarians and farmers.

1. A more extensive record of veterinarian activities should be kept by the provincial Department of Agriculture;

we found it difficult to obtain information on the extent of WMD, as the Veterinary Services Division had records of only those animals they received for examination.

2. There should be an increased dialogue between the federal and provincial departments and practising veterinarians concerning the best way to prevent WMD. Addition of selenium to feeds, especially to cattle feed, may not meet with universal approval if, as veterinarians believe, mineral supplements on prescription allow them more control in alleviating selenium deficiency.
3. We agree with the Department of Agriculture that fertilizer should be added to soils and preventative measures taken for selenium deficiency. Monitoring of forage for selenium and of soils for sulphur should be an on-going program. Only by knowing actual deposition quantities of sulphur or selenium content of vegetation can the Department of Agriculture advise the farmers on proper management.
4. Government should be more responsive to the concerns of the farming community and attempt to allay the fears of its members. Many farmers do not fertilize because they believe enough sulphur is being added by gas plants, or that combinations of fertilizer and gas plant emissions contribute to a selenium deficiency. An educational and informational program to outline what is known and suggest management practices would be most beneficial in this case.

This investigation has revealed a number of inconsistencies in our knowledge about gas plant emissions. While this may be peripheral to the central focus of this report on selenium (in fact, we view the case of selenium as only one segment of the emission question), we feel that some recommendations should be made here because of the importance of the issue.

1. A research program should be undertaken to determine the radial distribution of sulphur deposited by gas plant emissions. There is a need to study depositions closer to plants than the seven miles as reported by Walker, as much concern centers around the farming communities near gas plants. Studies that are presently being carried out by the gas industry may supply many of these necessary data. Complementing this program should be an analysis for selenium in vegetation.
2. An opportunity exists to determine future sulphur buildup in soils where new gas plants have been built. Knowledge of this sort is important if the long-term effects of sulphur deposition are to be evaluated. For example, a detrimental progressive increase in soil acidity has been postulated.
3. Total sulphation cylinders are situated immediately around gas plants. Apparently the data obtained from these cylinders are not easily related to ambient air concentrations, nor have they been used to determine the fate of emissions, be it absorption by vegetation or soil, or removal in precipitation. We recommend that research be undertaken to establish if a relationship between cylinder data and the various fates of emissions does exist.
4. Before new sour gas plants are constructed, it is recommended that the total environment be monitored for all the variables that are presently of concern. In the past the physical environment may have been monitored; we believe it is important to also have a knowledge of the social environment: the health and welfare of humans and other animals.

A list of references specific to the subject matter of this chapter is included at the end of this report as Appendix 4.

TABLE 1 SELENIUM IN TOP GROWTH IN FORAGE SPECIES (*)

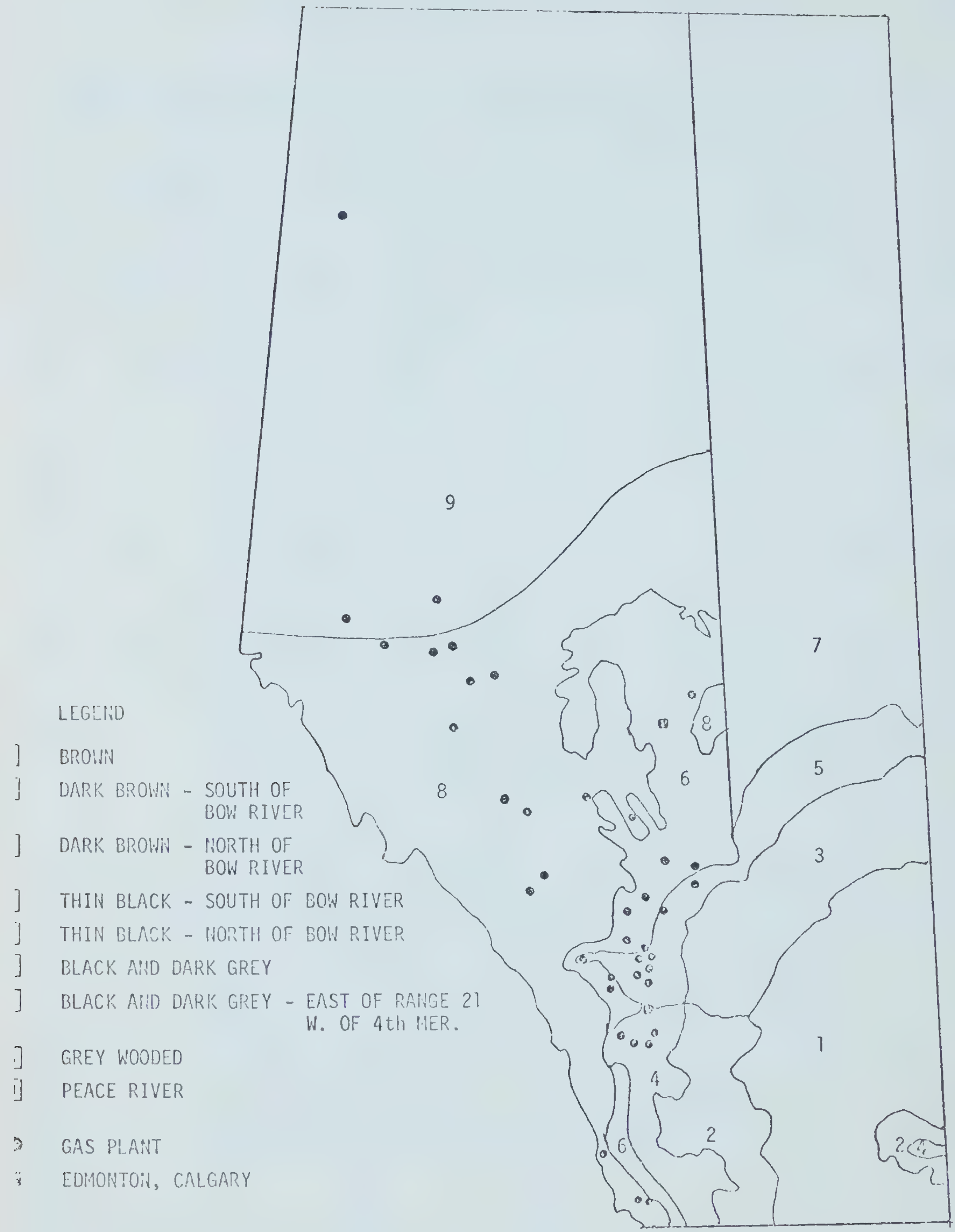
Species	Yield Response to S fertilizer	No. of samples	Ave. Se in top growth (ppb)	
			Without S fertilizer	With S fertilizer
alfalfa	yes	10	242	112.3
	no	13	112.5	78.5
alsike clover	yes	31	18	12.9
	no	7	24	14.7
red clover	yes	26	18.5	11.1
	no	4	8	6.5
bromegrass	yes	7	27.7	21.6
	no	8	30.8	26.4
timothy	yes	19	12	10.6
	no	6	11.7	9.0

(*) From Walker, D.R., Can. J. Soil Sci. 51, 506 (1971)

TABLE 2 SELENIUM LEVELS IN BARLEY GRAIN

Soil Area	No. of Samples	Percent of Samples Tested			
		<100 ppb	100 - 199 ppb	200 - 1000 ppb	>1000 ppb
1	24	16.7	12.5	62.5	8.3
2	33	18.2	9.1	66.7	6.1
3	44	11.4	25.0	59.0	4.5
4	21	19.0	28.6	52.4	-
5	68	23.5	42.6	33.8	-
6	109	71.5	16.5	11.0	0.9
7	31	51.6	45.2	3.2	-
8	30	80.0	16.7	3.3	-
9	34	64.7	17.6	17.6	-

FIGURE 1. SOIL ZONES AND SULPHUR EXTRACTION GAS PLANTS IN ALBERTA



5. SCIENCE ADVISORY COMMITTEE CRITIQUE

In order to obtain an informed objective commentary on the public hearings the Environment Conservation Authority invited its Science Advisory Committee to prepare a critique of the hearings.

In the ensuing chapter this report is presented in its entirety. It was prepared by the *Ad Hoc* Committee on Sulphur Extraction Gas Plants of the Science Advisory Committee to the Environment Conservation Authority and submitted under the title:

A Report On

The Matter of the Environmental Effects

of the Operation of Sulphur Extraction Gas Plants

At the time that the *Ad Hoc* Committee on Sulfur Extraction Gas Plants, hereinafter referred to as SEGP, was formed, it was envisaged that its task would be to advise the Environment Conservation Authority (ECA) with regards to hearings in general and to delineate the work to be done by consultants, to suggest consultants to be retained, etc. with regards to the preparation of a report or reports which would serve as the starting point for the hearings. It was anticipated that such reports would be made available to those wishing to appear at the hearings well in advance so that structured comments would be possible. However, subsequent to the formation of SEGP, it was learned that the retention of consultants would not be possible due to financial reasons. When it was pointed out that SEGP members, due to prior commitments, could not invest the time required to prepare the report or position paper which would serve as the starting or focal point of the hearing, SEGP was informed that the report would be prepared by Dr. R. Klemm of the Alberta Research Council who had been seconded to ECA by the Government.

At this point it was decided that SEGP would be provided with a copy of the Klemm position paper several months prior to the hearings so that it might provide ECA with commentary on the paper along with independent observations or suggestions either before or at the hearings. Unfortunately, due to unforeseen delays, SEGP did not receive the Klemm report until several days before the hearings. SEGP met and after discussing the situation came to the conclusion that due to a shortage of time, it could not prepare an appropriate report during the hearings. The committee concluded that it had some information at hand which should be made available to ECA and that it wished to present these along with comments regarding the Klemm Report at a later date. Consequently, it requested and received an extension from the Science Advisory Committee (SAC) so as to perform this task.

After receiving the extended period requested SEGP decided to prepare a report which would consist of commentary on:

a) the Klemm Report,

b) briefs presented before the hearing,

c) certain matters studied independently by various SEGP mambers, and

d) matters related to the problem and to public hearings in general.

The following, then, is a presentation of the Committee's view in these matters.

5.1 THE KLEMM REPORT

The Klemm Report falls short of what the situation required, for it not only neglects some important areas but in general deals superficially with those topics which are discussed.

For example:

1) The report makes essentially no recommendations.

2) No reference is made as to the possibility of errors or shortcomings by government or government agencies.

3) The report admits to an inability to separate the sour gas contribution from that of the entire industry (p.3), then proceeds to deal with conventional economics in a rather confusing if not misleading manner. For instance, it states that the cumulative capital investment for the gas industry is $8000 million. It then states that this figure is misleading without clarification (p. 7). It then goes on to cite figures for the entire oil and gas industry without stating what proportion of total investment or expenditure is attributable to the sour gas section (p. 9). The matter of employment in the sour gas sector is estimated at 5,000 (p. 4); however, a multiplier effect is cited in order to indicate that many more are employed indirectly. The report not only fails to indicate the magnitude of that effect on the economy but makes the sweeping statement that it is inestimable (p. 9). Furthermore, it is suggested that due to marketing effects and its unique position as a by-product, Alberta sulphur can partly be held responsible for the drastic drop in prices (p. 10). This would appear an understatement, for in the opinions of economists the current "sulphur surplus"

and low prices represent a classical example of the law of supply and demand.

4) The report makes no reference to a large and expanding body of knowledge which is central to the whole problem and is commonly called resource or environmental economics.

5) Although the sulphur cycle is mentioned in the general reference (p. 13) it is not fully dealt with in the report (1).

6) Not only are the sections dealing with plant processing superficial, little attempt is made to cite references which would permit the reader to extend his knowledge; e.g. it would have been appropriate to mention, "The H_2S Route to Sulphur Recovery from Base Metal Sulphides; Part II: The Recovery of Sulphur from Cases Containing H_2S", by R. F. Pilgrim and T. R. Ingraham, Mines Branch Info. Circular IC243, June, 1970, Department of Energy, Mines and Resources, Ottawa; which is a current review containing over 100 references.

7) Parts 7 and 8 of the report represent the "critical" chapters, but aside from statistics, guidelines, etc. they must be regarded as representing a qualitative treatment of a quantitative problem, e.g.:

a) Until several years ago, most plants were having difficulty in demonstrating overall sulfur recoveries in excess of approximately 92%. They currently talk of recoveries as high as 97% through the use of 3rd and 4th stage catalytic converters. Since the upper limit on recovery can be estimated thermodynamically, such estimates should be made to verify proposed or cited recoveries and to indicate what may be possible with and without additional clean-up processes (2).

b) It is difficult to express confidence in reported sulfur recoveries because of inherent errors in analytical determinations, incomplete knowledge of reaction chemistry (when dealing with $H_2S/SO_2/COS/CO_2/H_2O/S$ contents which are significant relative to one another) and the methods employed in computing recovery (3).

9) Sections of Part 8 dealing with tail gas clean-up reflect the fact that the technology of the processes is dependent upon empirical data obtained from plant operators and that as a result much uncertainty surrounds existing and proposed processes.

10) Section 3.8 of the report is not convincing, at least in the form presented. It should have traced a material balance calculation in more detail and shown quantitatively what effect the various errors represent (4).

11) The second paragraph on page 39 states that the Energy Resources Conservation Board maintains close liaison with the Canadian Petroleum Association, the Independent Petroleum Association of Canada and the Canadian Association of Oilwell Drilling Contractors and that committees from these agencies work with the Board so as to arrive at reasonable regulations. However, there appears to be no effort made to liaise with research scientists at Alberta's Universities, prior to the establishing of guidelines, an important omission by the Board.

12) While the report lists sources and effects of other pollutants, some of these have little if any relevance to the sulphur extraction process, e.g. lead and mercury, and tend to detract from the main objectives of the report.

13) The material in Parts 10 and 11 infers that a great deal is known about the direct toxic effects of SO_2 on animal and plant life, when in fact the effects on animal life are not well understood and those on vegetation and crops in the vicinity of sulphur extraction gas plants have scarcely been looked at.

14) No mention is made of possible acidification of soils, surface waters and rainfall by the absorption of SO_2. (These effects have been found in industrialized areas with high levels of SO_2 emission, e.g. Western Europe and Northeastern U.S.A.) (5).

15) The possibility that Alberta's special meteorological conditions (low temperatures, unusual inversion characteristics, etc.) may exacerbate any problems is not mentioned.

16) Section 1.2 contains minor errors, i.e. the statement that the Turner Valley field had already been delineated in 1914 (6); and the suggestion that crude oil production continued to expand throughout the 1940's (7); In the last sentence of the section it is inferred that industry anticipated problems, and was concerned with regard to pollution

and that this concern prompted the initial recovery procedures. However, since the initial total recovery was only 30 long tons per day (LTD), and industry appears to exhibit little concern over the current emission of 600 LTD or the predicted doubling of this rate during the coming decade, it would seem that this inference may be unwarranted.

The shortcomings of the report may be attributed to two factors, mainly: the short period available for study, and an apparent lack of familiarity by Dr. Klemm with the area, probably occasioned by the very general nature of the topic. SEGP believes, however, that the author did as well as could be expected under the circumstances and it respectfully submits that the task should not have been performed by a single individual, but that it should have been assigned to a group of consultants with in-depth expertise in the many and varied aspects of the problem.

5.2 The C.P.A. Brief

Even before one reads the C.P.A. brief, one is struck by the contrast in the method of attack employed by this body as compared to that of the Government in preparing the position paper. Industry selected a task force of 13 of its most experienced employees to prepare their position paper. Furthermore, the task force was provided with the services of five consultants. In other words, industry assigned a great deal of time, talent and money to what they appear to have felt was an important task. On the other hand, the Government chose to economize on all three aspects.

A detailed examination of the C.P.A. study reveals a defensive position, one which may be typical of anyone who puts to private use what is referred to by economists as a common property resource.* That

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*Common property resources are those valuable attributes of the natural world which cannot be, or can only imperfectly be reduced to individual ownership and thereby do not enter the processes of market exchange and the price system.

is, the brief tends to overemphasize the public benefits and under-emphasize real or possible public disbenefits. For example:

1) The C.P.A. brief questions the relevance of the study of ownership and employment, points which are not only relevant but quite important in our opinion.

2) The intimation that high exploration costs and the added cost of more efficient sulphur removal will inhibit and/or delay development may appear obvious, but close scrutiny would suggest that this may not be the case. During the past decade sulphur production has increased while price has decreased to one-fourth of the all-time high and production is only at one-half capacity. This indicates that the price of sulphur does not appreciably control its production. Reduction in development rate has resulted from failure to discover additional reserves (see Klemm Report, p. 6). From this, it may be seen that lack of new discoveries and existing overcapacity will not permit additional development in the near future. On the other hand, the energy crisis will in all probability force the development of newly discovered reserves with or without a sale for sulphur.

3) The brief emphasizes low sulphur prices and oversupply and the associated economic difficulties (section I-C); however, there is no indication that these were matters over which industry in fact had control.

4) Under the heading "Economic Benefits to Alberta" are cited a variety of gross figures, e.g. gross production revenues from natural gas, total industry revenue, percentage of total personnel income due to industry, percentage of GNP, etc. Unfortunately these gross figures do not show the actual benefits to Alberta. This may seem like a minor point; however, let us suppose that in one case we have an Alberta-owned firm which uses local capital, know-how and equipment to build and operate a gas producing and processing facility; and in the second case, a foreign-owned company uses foreign capital, retains foreign knowledge to design and purchases foreign-made equipment to establish an identical facility. There is no question that both would benefit Alberta but

there is also not any doubt that they would <u>not</u> benefit the province equally. To infer that total expenditures are in fact a measure of benefits is therefore misleading.

5) It is implied that safety practices are beyond reproach. To back this up, a table (I-6) listing Workmen's Compensation Board Assessment Rates is presented without explanation. However, the Alberta Federation of Labour presentation at the Edmonton hearing stated that of 337 accidents in three years in this industry, there were 50 fatalities. This would suggest that the table cited may very well be a measure of variables other than safety and hence is not an appropriate measure of safety practices.

6) The brief attempts to detract from the fact that the sulphur emission is now at 600 LTD and may well rise to about twice that during this decade (see P. I-1) by suggesting that this represents but 3 lbs./acre when distributed over the province (see P. I-2) and infers that even this amount does not make up for the soil sulphurdeficiency (see P. II-4). It ignores, however, the observation that 20-60% of the SO_2 is deposited in the immediate vicinity of the emission source (see Klemm Report, p. 48). Furthermore, the observations of Summers and Hitchon show that a considerable fraction of SO_2 from at least one plant was deposited within a 25-mile radius (see p. VIII-4). Hence the C.P.A. statement is deliberately misleading.

7) The brief states that selenium and lead have never been detected in gas plant waste streams but it fails to state whether or not detection of these elements is routinely attempted or the means of attempted detection. As a result, there is no way of knowing the true significance of the statement, e.g. it could mean that selenium detection is not attempted, or that selenium does not appear in H_2S-containing natural gas accumulations, or that it does occur, but is completely removed in the treating process. The statements in part E, Summary, with respect to 2) Animal Life, are confusing and contradictory. They imply that SO_2 levels in gas plant air pollution incidents did not contribute to the morbidity or mortality, since controlled laboratory tests show that similar exposures

had no effect or that animals are less susceptible than humans. In fact, in other air pollution incidents (9) morbidity and mortality data have been correlated with indices reflecting SO_2, particulates, and sometimes other pollutants. Further, with regard to humans the individuals affected are usually those who already suffer from respiratory difficulties (bronchitis, emphysema, etc). There is thus the necessity to consider prolonged (chronic) exposure, exposure to combined pollutants, susceptibility with respect to age, disease, etc. Hence the implication by the report that gas plant SO_2 emissions are innocuous is not supported by available data.

8) No mention is made of the fact that sulphur, like natural gas, is a non-renewable resource and should be conserved.

9) The last paragraph of section B on page II-9 is somewhat vague. If the paragraph is intended to indicate that the additional recovery of a non-saleable product does not make sense the observation is correct. But that is not all that is involved. If it were the only consideration, the question would not be whether additional recovery is warranted, but whether or not existing recovery is.

10) The C.P.A. brief attempts to demonstrate that ambient air quality rather than emission standards should be used and that the current Alberta ambient standards are more than adequate. The evidence presented is not convincing. With regard to the first point, it must be noted that although ambient standards may be convenient and acceptable to industry, such standards pose serious problems with regards to monitoring, enforcement, and division of responsibilities. The position taken, that current ambient standards are adequate, may be based not only on industry's reluctance to spend additional money when the true benefits which would be realized are not only unknown, but also because these benefits would accrue to others.

5.3 OTHER INDUSTRY BRIEFS

A viewing of the remaining industry briefs indicates that essentially the same position is taken as that taken by C.P.A. It should be noted,

however, that a variety of what appear to be contradictory statements appear in these briefs, i.e.:

1) The Petrogas and Canadian Occidental presentation in Calgary stated that (a) total environment around the plant has not deteriorated in eleven years, (b) slight sterilization of soil near the plant was observed, and that (c) it was possible that 10 lbs./acre/year of SO_2 may come down within a 20-25 mile rectangle in which the plant is located. This represents an SO_2 emission from the stack of 3.9 LTD. However, the daily average emission from the Petrogas plant is approximately 100 LTD (the maximum allowable being 200 LTD). This accounts for but 3.9% of total emission at this time. This figure appears to be extremely low compared to the observation by Klemm (p. 48) and Summers and Hitcheon (C.P.A. submission, p. VIII-4).

2) The Petrofina brief (Calgary) stated that environment has not suffered and makes reference to the building of a picnic area and the increase in land values. However the implications of these statements should be carefully examined in relation to the externalities* in this area.

3) Holmes' presentation on behalf of Texas Gulf Inc. indicated that there are very few documented cases of SO_2 stress in natural native stands of trees or crop plants, but admitted that his company had noted stress on ridge crests and hillsides facing plants, that severe damage was noted near sulphur vats and that mould stress was found in poplar and ash trees.

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*Externalities arise when a party other than the producer or consumer of a good, what we call a third party, incurs benefits or suffers losses as a result of production or consumption of a good and proper compensation is not extracted from the third party beneficiary or paid out to the third party loser. As can be seen from the above definition, two types of externality exist. External economies, as economists refer to them, occur when the third party is a beneficiary, while external diseconomies arise when the third party suffers a loss.

4) The Amoco (Calgary) presentation makes the point that their current recovery of 96% requires increasing to 98.2% and that they wish to retain current practices since upgrading will inflict an economic burden. However, they make no statement regarding potential reduction in disbenefits due to increased treatment, relative to added cost.

5) The Gulf Oil (Red Deer) presentation stated that their plant had used monitoring since 1957. It went on to observe that there should be more co-operative research rather than a modification of regulations. They did however admit that they did not have an active environmental research program but were contemplating one. A 15-year period for contemplating research would appear excessive and leaves little for its initiation and execution.

6) The Whitecourt Environmental Study Group* stated only mild stress on poplars and mild local effects. They suggest that SO_2 effects appear to be transitory and that no permanent damage exists near plants in operation for 10 years. They further suggest no effect on animals. It was stated that dust from the sulphur stockpile has had no effect during a 10-year period in the Windfall area. The conclusions reached by this study group are misleading. The observations made regarding plant and animal life after ten years may merely mean that certain species can survive, will even flourish in an SO_2-bearing atmosphere and that others which cannot have long since died or moved. On the other hand, the poplar tree, having a long life growth span, does show some effects.

7) The Chevron Standard brief (Whitecourt) tends to emphasize external benefits such as vehicle access to wilderness and availability of airstrips and roads for fire fighting. It makes no comment regarding effect of roads, etc. on animal population (i.e. licensed human predation, which cannot be easily regulated). Under questioning they admitted to an inability to state how much it costs to produce sulphur.

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*This is a study group formed by operators of plants in that area.

8) The Amoco Brief (Whitecourt) indicated only mild and temporary effects although emission is about 150 LTD with a maximum allowable of 210 LTD. That such rates of emission would cause but mild effects seems hard to believe especially when one is led to believe that the initial Jumping Pound plant recovered only 30 LTD. To appreciate the significance of the point being made it is necessary to realize that the emission rate in this one instance is between 1/4 and 1/3 of the Alberta total. This in turn must be compared with the C.P.A. statement regarding a fallout of 3 lbs./acre/year for the entire province. Although the group was unable to say what the actual cost of sulphur production was, it was convinced that additional recovery was economically inadvisable. This point is demonstrated using a figure of 50 LTD at a value of $40,000. If however, the sulphur price of $7.50/ton suggested by Klemm (p. 10) is valid, the example used does not accurately relate the situation (50 LTD at $7.50 would yield about $140,000). The brief also refers to a selling price of $13.00/ton which further confuses the issue.

9) The GCOS brief (Edmonton) states that plant has had no effect on environment. This seems hard to believe when it is realized that plant vents about 50% of the maximum permissible of 340 LTD of SO_2 from the power plant and 40 LTD from the recovery plant.

5.4 OTHER BRIEFS

In view of the City of Calgary's economic dependence on the petroleum industry the brief presented by that city's Chamber of Commerce represents a reasonable and expected position. However, the position taken does not necessarily reflect the views of the citizens of Calgary in general.

Most of the remaining briefs express concern over the effect of plant effluents on the environment. The points raised are numerous and varied, and together they suggest that:

1) There appears to have developed a creditability gap between employees of government departments, boards, etc., and those contacting

them with regards to incidents which are alleged to indicate adverse effects due to plant effluents.

2) There is evidence of some adverse effects as is indicated by:

i) Corrosion.

ii) Respiratory and other difficulties in humans and animals.

iii) Soil acidification.

iv) Tree burns, etc.

v) Decreases in land value and saleability.

vi) Animal migration away from long-established habitats.

3) There is a need for detailed study of the entire matter.

4) The use of averages in establishing emission, ambient or other standards may not offer protection to living organisms. Upper limits in addition to averages would be more appropriate.

One brief (ICEQ, Edmonton) refers to the areas of resources or environmental economics, e.g.:

i) It presents an oversimplification of the concept of external disbenefits or external diseconomies.

ii) It suggests that all costs and benefits including special costs should be studied.

iii) It infers that external costs should be internalized. However, traditional resource economics hold that this is inappropriate.

iv) It refers to the disadvantaged layman, i.e. the situation where the exploitation of a private good results in externalities affecting a common property resource.

v) It also refers to the need for study of interactions in complex systems.

The ICEQ brief refers to reported illness by those living near points of sulphur compound emission and while it is careful to indicate that it doesn't wish to judge whether or not such illnesses are organic or psychosomatic, it could have pointed out that either form of illness could still be considered a disbenefit to the sufferer.

5.5 OBSERVATIONS AND SUGGESTIONS

It is obvious that there are two opposed groups and that in many instances the charges made by the one are countered with positive claims by the other. Industry contends that gas plants have not caused land values to suffer whereas farmers, ranchers and Municipal Councils insist that such plants have reduced the value, saleability and subdivisibility of such lands. These statements in themselves prove nothing. However, when it is realized that land values represent a key variable in benefit-cost analysis, the statements indicate that investigation of this matter is in order. In similar fashion, industry indicates that wildlife migration from long-established habitats as a result of plant effluents is not common whereas others contend the opposite. This suggests another possible disbenefit which may be used to establish or measure externalities, especially where a monetary indicator is not available.

5.5.1 Effects of Air Pollutants on Living Organisms.

The ICEQ brief suggests, as did others, that field survey of inhabitants should be undertaken. Although such a survey may shed some light on the matter, the results obtained may yield more opinion than fact and may as a result provide an insufficient basis for embarking on a larger ecological multidisciplinary research program. Such programs should probably not be funded before a reasonable amount of quantitative information is available. It may therefore be most prudent to proceed with simple obvious investigations not yet undertaken, e.g. set up projects to determine direct effect on vegetation, soil, animal life, etc. This could be accomplished through biological monitoring, etc.

For example:

i) Exposure of small sensitive animals (including insects) may be useful as monitors in emission zones and comparison with those in a control area (mice, chickens, etc.).

ii) Determination of pH, sulphate and elemental sulphur in soils should be obtained periodically on samples taken from defined sites.

iii) Exposure of sensitive plants in emission zone and comparison with a control (barley, alfalfa, lichens, etc.).

iv) Periodic analysis of surface water to test for acidification by direct absorption of SO_2.

It appears that detailed material balances on gas plants have yet to be obtained. The fact that sulphur compounds are abundant in effluent streams is not sufficient evidence that they and they alone are responsible for the alleged harmful effects. For example, the agricultural segment presents some evidence of effect on plant, animal and human life. On the other hand, industry states that this is not due to emission from plants and supports their statement with evidence that in laboratory tests levels of each of the sulphur compounds much higher than the current standards have produced no ill effects on test species. There are a variety of explanations for such a situation.

1) The effects cited by the agricultural segment are not due to effluents from processing plants.

2) The effects cited are due to processing plants, but compounds other than those of sulphur are responsible, e.g. compounds in trace amounts.

i) Compounds other than those of sulphur are responsible, e.g. compounds in trace amounts.

ii) The effects are due to sulphur and other compounds acting synergistically, e.g. sulphur and some others; compounds may be toxic only when both are present.

iii) The effects are due to upper limits being exceeded for short periods of time, even though the average emission is not affected.

It is therefore suggested that a detailed material balance should be applied with analysis for trace amounts in streams for at least one plant and that the possibility of synergistic effects be examined in a laboratory situation.

There appears to be some uncertainty on the short- and long-term fate of emitted sulphur compounds. This matter should be studied. For example, the lay agricultural segment refers to adverse effects to soil whereas industry refers to sulphate and sulphur fallout as a benefit for sulphur-deficient grey wooded soils and back this up with general scientific evidence. Unfortunately, the evidence cited refers to effects observed primarily on legumes, despite the fact that little evidence is presented that fallout actually occurs on soils which are deficient in sulphates and are used to produce legumes and that magnitude of fallout is appropriate to provide none but beneficial effects. Furthermore, the suggestion by industry, again backed up by scientific evidence, that excess sulphate fallout can be overcome by the application of lime takes no account of the fact that the application of lime to a cultivated land represents a disbenefit to the farmer and in the case of forested land is not only a disbenefit but may well be impractical.

Most of the discussion presented in the briefs appears to deal with soil as more or less an inanimate inorganic stratum of agglomerate matter capable of absorption and chemical reaction. It is also a living system composed of micro-organisms (i.e. fungi, bacteria, protozoans); hence it is a very active and animate medium.

In all of the submissions there appears to be little mention of, or appreciation for, the fact that for both plant and animal life certain substances serve as metabolites whereas others are end products of metabolism and still others are required in trace amounts. These may appear to be academic matters; however, it must be noted that a deficiency of a metabolite may stunt growth, the overabundance of an end product of metabolism may exert a feedback inhibition effect and a compound necessary to metabolism in trace amounts may be toxic at high concentration. It is therefore improper to assume that a compound is responsible for harm caused to living organisms just because it is in abundant supply or, conversely, that it may not be responsible for harm when it is present in trace quantities only.

No real concern was expressed at the hearings with possible long-term effects of sulphur plant emission pollutants on plant life. Such effects, were they to occur, might not be spectacular or dramatic, but rather may consist of gradual and permanent alteration of metabolism in plants, e.g. phenotypic or genotypic alterations. The implications of such effects are very significant; consequently, this area requires more basic research.

5.5.2 Monitoring and Control

Certain matters referred to in the Klemm Report would appear to require immediate attention, e.g.:

i) The comments regarding adequacy of stack heights (pp. 50-51) should be examined and the design techniques studied.

ii) The statement that no test is made for completeness of combustion in stacks (p. 51) should be checked and if true the situation should be remedied.

iii) Matters dealing with the use of trailers (p. 54), monitors (p. 52) and exposure cylinders should receive immediate attention. (It should be pointed out that there have been statements by others to the effect that trailer intakes are usually positioned 10-12 feet above ground level and this may be improper when testing for ground level concentrations.)

iv) The practice of using spent catalyst as road paving material (p. 58) should be examined with regards to leaching, etc.

v) The composition of gas plumes (p. 65) should be obtained. With regards to atmospheric dispersion in monitoring, the following observations are worthy of note:

a) There appears to be a lack of application of engineering or scientific methods in the making of so-called "truth" measurement. It is a well-known fact that it is not always necessary to measure something in order to know that it is there. This applies in particular to stack

gas "truth" monitoring. For example, rather than measuring gas composition and flow rate in the stack, the monitoring of tail gas, fuel and air into the incinerator may prove to be an easier and more reliable way at arriving at the desired information.

ii) The current practice employed for determining ground level "truth" pollutant concentration consists of monitoring at a single point some distance from the plant. However, the aspect ratio of plumes is such that the length exceeds the width by an order of magnitude so that the angular width of a plume is about 10°. Consequently, a slight shift in wind may shift the plume out of reach of the monitor.

This matter could be rectified by studying the behaviour of plumes, in areas where such behaviour is not too erratic, and placing several monitors at approximately selected points. In this regard, the observations made by such people as W. Gussela at the Calgary hearing might be used to study the behaviour of plumes. On the other hand, in areas of complicated local micrometeorology a high meteorological tower might be placed near a plant in order to study conditions. Such results, along with those obtained from monitoring, might be used as input data for computer model study.

In the cases where plants are in the foothills and close to mountains the conditions are much more complicated and would therefore require additional field work before an observation tower - computer approach could be implemented for the calculation of pollution levels.

There have been recommendations to the effect that ground level monitoring could be combined with throughput control so that high levels of pollution could be avoided. Such methods appear to be questionable in view of response lag, length of time required for plant stabilization and normal duration of severe climatic disturbances. On the other hand, throughput control based on short lead time local weather forecasts might prove effective.

5.6 SOME GENERAL OBSERVATIONS REGARDING THE HEARING

An examination of the various briefs presented indicates that on the one hand, farmers, ranchers, and those concerned with the environment are of the opinion that the processing plants in question do pose environmental problems which require study in detail; and on the other hand, industry is of the opinion that no real problem exists and that the status quo should be retained since it is inadvisable to invest in clean-up equipment when no real benefit will be obtained as a result. However, the non-industry side is well known and it does not require a public hearing to establish industry's reluctance to invest in ventures without a positive trade-off. The question then is, of what real value were the hearings?

It appears that the benefits to be derived are to be found in unexpected areas. For instance, the hearings did not establish whether or not a pollution problem exists. However, they did show that such matters cannot be established except by detailed study.

The hearings showed a rather large contrast between the effort and money employed by industry to present its side as compared to that by individuals or small groups, or by government in preparing a position paper. It would appear that the decision to save money by not retaining a group of consultants to prepare the position paper is a mistake which should not be repeated. This same contrast shows very clearly one of the major problems in a situation of this sort, namely the inability of individuals and small groups to present their side of the picture in as professional a manner as that of industry.

The reference by several people to the loss of credibility of members of government boards and bodies, coupled with what would appear to be careful avoidance of consideration of the role of government or employees of the government appears to be a serious matter for two reasons. The credibility gap must be closed by either changing tactics or setting up machinery for dealing with farmers, ranchers, etc. by some body sufficiently removed from government so that credibility can be maintained.

On the other hand, the suppression of evidence may render impossible solutions of technical problems.

Aside from the reference in the ICEQ brief to externalities and the work of Bonnett and Gill (10, 11), there appears to be a complete lack of appreciation for the fact that one aspect of the problem falls into a discipline referred to as resource or environmental economics. Although this discipline represents a new body of knowledge, it is nevertheless a sufficiently large body of knowledge so that it cannot be discussed in detail in this report. Even so, its significance warrants some discussion.

Some of the important principles involved in this discipline may be appreciated by referring to a recent text entitled Economic Growth and Environmental Decay; the Solution Becomes the Problem, by Barkley and Seckler (12). Some pertinent quotations from this text are gathered together in an Appendix to this report. These quotations are not only interesting in their own light but have a direct bearing on the problems under study. For example:

1) An understanding of the nature of private and collective goods leads to an understanding of the imbalance in time, money and effort employed by industry and others in the preparation and presentation of briefs. To fully appreciate the reason for the imbalance, one must also understand Canadian tax law. Thus, whereas the industry side is prepared by people obtaining compensation and whereas the entire cost of the presentation may be tax deductible, the non-industry side is prepared by people who in many instances not only must expend effort without compensation but must incur costs which in most instances are not tax deductible. Consequently, the imbalance noted should not be ignored or treated as an oddity but must be accepted as something to be expected in all hearings where measures are not taken to rectify the situations.

2) An understanding of economic feedback loops clearly shows that the avoidance by the Klemm Report of matters of foreign ownership, employment and exports, etc. was inappropriate. Furthermore, the request by the Chairman of the Environment Conservation Authority, at the Edmonton

hearing, that the C.P.A. delete its reference to such matters was not only improper but could be interpreted as setting a dangerous precedent. For these matters are not solely political in nature. It does make a difference as to who obtains the benefits and who pays the costs, and it does make a difference as to who consumes the goods. Consequently, such matters must be considered to be technical matters first and political matters second. It must therefore be appreciated that this matter, although thorny, must be dealt with.

3) The intervention of government or government agencies so as to close a feedback loop merits special attention for the case in point. The evaluation of externalities does not merely involve an assessment of whether or not harm is being done to local residents and/or the surrounding plant and animal life, but must involve the evaluation of the direct, and if possible, the indirect cost of such effects. Among the indirect costs are those incurred by government and government bodies in hearing, investigating and processing complaints, the conducting of public hearings, etc. Indeed, a detailed study of this matter is a technical prerequisite to political action, for without this information base the internalizing of external cost, etc. could prove not only a futile exercise but could well lead to economic disaster.

4) To conduct hearings into royalty structure, wellhead pricing, environmental effects of sulphur extraction gas plants, subsidizing research into new uses for sulphur (17), etc. without due regard for the manner in which these acts or problems are interrelated, is technically unsound.

5) Although the hearings may tend to give the impression that recommendations regarding the evaluation of externalities, environmental impact and the use of material balance concept are but novel suggestions, these are in fact well-established techniques in the field of environmental or resource economics (18-20).

The real need for detailed study with regards to the Environmental Effects of Sulphur Extraction as well as those problems to be encountered in other hearings may be sensed from the observation of Barkley and Seckler,

"It is difficult for a society to know where it is going until it knows where it has been," (21). By the same token it is virtually impossible for a society to properly decide which way to go when it does not know where it is at.

A list of references and special appendix
to this chapter is included as Appendix 5
at the end of this publication.

6. CANADIAN PETROLEUM ASSOCIATION EPILOGUE

Following the presentation of their submission at the Edmonton session of the hearings, the Canadian Petroleum Association offered to present the Authority with an epilogue to their submission if the Authority considered that this would be helpful.

The Chairman of the Authority accepted this offer and the epilogue which was subsequently received is reproduced in its entirety in the following pages.

6.1 TRANSMITTAL LETTER FROM C.P.A. TO ENVIRONMENT CONSERVATION AUTHORITY

ALBERTA DIVISION
CANADIAN PETROLEUM ASSOCIATION

IN W. PROCTOR
MANAGER

625, 404 SIXTH AVENUE S W
CALGARY 1, ALBERTA
TELEPHONE 269 6721

December 5, 1972

RECEIVED
DEC 07 1972
ENVIRONMENT CONSERVATION AUTHORITY

Dr. W.R. Trost, Chairman,
Environmental Conservation Authority,
9912 - 107 Street,
Edmonton, Alberta
T5K 1G5

Dear Dr. Trost:

CPA Epilogue on Public Hearing
Sulphur Extraction Plants

As indicated during the public hearing on "The Environmental Effects of the Operation of Sulphur Extraction Gas Plants" held in Edmonton, October 19, 1972, we now enclose an epilogue which summarizes the Canadian Petroleum Association's views on the subject matter.

In addition, in view of the intended impact of the Authority's hearings on new legislation with long-term ramifications, we would like to make the following general observations regarding the conduct of future hearings.

1. All oral submissions should be complemented by a written submission, available to the public at the time of the presentation. Where this proves impractical, every effort should be made by the Authority to summarize during the hearing, the points made, so that the public and the Authority have the same understanding of the presentation, following presentation and/or examination of same.

2. We recommend that the Authority empanel relevant technical experts who would be given proper latitude to explore all submissions in depth, in order to supplement the Authority's examiner role.

.........2/

We would like to express our appreciation to the Authority for their very courteous and extended examination of our submission. We trust that our participation in the hearings will serve to further the mutual interests of the public , industry and government.

Yours very truly,

John W. Proctor,
Manager, C.P.A.

JWP:ja

6.2 EPILOGUE

The Canadian Petroleum Association presents the following matters for consideration by the Environment Conservation Authority before final recommendations are made to the Minister of the Department of the Environment.

1. The related and respective roles of the Department of the Environment and the Energy Resources Conservation Board should be clearly defined by government policy statement. The Department of the Environment should set the environmental standards for the petroleum industry and the Energy Resources Conservation Board should administer them.

2. It was unfortunate that no direct input to the hearings was forthcoming from any government agency or department other than through the Klemm report. Relevant government statements for public purview would be of considerable interest, and useful to the Authority.

3. Non-energy mineral resource recovery efficiencies are not normally specified by government regulation. Sulphur is not an energy resource and within this principal parameter we question the wisdom of the Energy Resources Conservation Board involving itself in production and recovery efficiencies.

4. The limitation and monitoring of 'total sulphur' emissions from the stack of a sulphur extracting facility are considered acceptable practices required of the industry, and are used in the sulphur balance and plant material balance calculations.

5. 'Total sulphur' stack emission limitations (tons S_2) should be clearly separated from sulphur stack emission concentrations (ppm SO_2).

   Beyond the 'total sulphur' stack emission limitations, which primarily perform a conservation function, and a coincident role in limiting pollution capability, the only meaningful measurement related to environmental conservation is the concentration of the relevant effluent at ground level, and comparing that to the prevailing ambient air quality standard.

6. The intensity or sophistication of any particular monitoring program should only be based on the need to meet such uncertainties as may be uniquely observed, and then applied within the existing general standards.

   Industry has enjoyed the opportunity in the past to negotiate its uniqueness for a particular application before the appropriate government agency and within the existing standards and regulations, having due regard for all the pertinent scientific, technical, and other facts. The continuation of this policy should be confirmed.

7. Such research projects as were mentioned during the hearings represent only a portion of the total research effort of the industry.

We recognize the possible need for joint industry/government research projects, particularly as they may relate to areas of mutual interest and public concern and therefore recommend the establishment of an industry/ government task force to review joint research possibilities, at an early date.

The results of any jointly-funded research may provide the type of scientific and technical input required to substantiate existing or proposed legislation.

8. Finally, we wish to reiterate the industry's willingness to join with any governmental agency in discussing the possible establishment of new guidelines, regulations or standards.

We hope that no new guidelines or changes in standards will be established unilaterally by government. This would avoid the imposition of any sudden demands on the industry without sufficient lead time to assess any new situation or defend the status quo as may be deemed appropriate by industry, based on good, supportable, practical common sense and scientific evidence.

Calgary, December 6, 1972

7. APPENDICES

APPENDIX 1

LIST OF BRIEFS PRESENTED

PRESENTED AT PINCHER CREEK

Organization	Presented by
Saratoga Processing Co. Ltd.	D.J. Green
Oil, Chemical and Atomic Workers of America	R.C. Basken
Shell Canada Ltd.	R.G. Naden
Canadian Petroleum Association	J.G. Gainer
Private	Mrs. J. Taylor
French Petroleum Institute	J.W. Andrews
Pincher Creek Industrial Research Pollution Committee	B. McRae
Municipal District of Pincher Creek	H.R. Pharis
Gulf Oil Canada Ltd.	R.A. Thompson
Private	Mrs. G. McRae
William Main Family	Mrs. W. Main

PRESENTED AT RED DEER

French Petroleum Institute	J.W. Andrews
Private	Mr. L. Chandler
Mrs. R.H. Ross	Mrs. L. Chandler
Private	Mr. C. Robinson
Chevron Standard Ltd.	E. Cudby
Alberta Fish and Game Association	H. Lembicz
Alberta Association of Municipal Districts and Counties	A.E. Wigmore
Private	Dr. W. Sutmoller

Organization	Presented by
Gulf Oil Canada Ltd.	R.E. Pauls
Private	S.C. Nelson
Canadian Petroleum Association	H.W. Becker
Private	Mrs. T.E. Lynn

PRESENTED AT WHITECOURT

Whitecourt Environmental Study Group	E. Baranuk and Dr. R. Holmes
Canadian Petroleum Association	M. Winning
Chevron Standard Ltd.	J. Spring
Town of Whitecourt	Mayor J. Dahl
French Petroleum Institute	J.W. Andrews
Amoco Canada Petroleum Co. Ltd.	A. Neidermayer
Pacific Petroleum Ltd.	W.D. Broughton
Hudson Bay Oil and Gas Co. Ltd.	H.W. Becker
County of Lac Ste. Anne	J.B. McDonald

PRESENTED AT CALGARY

Canadian Occidental Petroleum Ltd. (Petrogas Processing Ltd.)	W. Chalmers C. Sibbald
Town of Okotoks	Mayor P.B. Milligan
Canadian Petroleum Association	J.E. Baugh
Private	M. Gusella
Private	Dr. C. Ekstrand
French Petroleum Institute	P. Bonnifay

Organization	Presented by
Era Instruments Ltd.	Dr. R. Holmes
Private	Mrs. E. Tennant
Petrofina Canada Ltd.	E. Wishart
Calgary Chamber of Commerce	J. Poyen
Texas Gulf Inc.	E. Plum and Dr. R. Holmes
Summer Village of Ghost Lake	Mayor W.G. Milne
Amoco Canada Petroleum Co. Ltd.	A. Neidermayer

PRESENTED AT EDMONTON

French Petroleum Institute	P. Bonnifay
S.T.O.P. (Save Tommorrow, Oppose Pollution)	Mrs. L. Swift
Great Canadian Oil Sands Ltd.	F.A. Bain
Alberta Federation of Labour	H. Kostiuk
Unifarm	J.R. McFall
Federation of Alberta Naturalists	Dr. J. Powell
Northwest Region of the Department of the Environment (Federal Government)	Dr. H. Etter
Canadian Petroleum Association	J.G. Gainer
Private	W. Geddes
Alberta Institute of Agrologists	R.E. McAllister
Private	Dr. P. Summers
Interdisciplinary Committee on Environmental Quality	Ms. P. Bonnett
National and Provincial Parks Association of Canada - Edmonton Chapter	R. Walsh

Organization	Presented by
Private	Miss M. Gawlak
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APPENDIX 2

SULPHUR DIOXIDE AND FOREST VEGETATION

by

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NORTHERN FOREST RESEARCH CENTRE

INFORMATION REPORT NOR-X-49

DECEMBER 1972

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1. INTRODUCTION

The purpose of this report is to bring to the attention of agencies concerned with atmospheric pollution control as well as gas industries, the effects of sulfur dioxide on forests. Particular emphasis is placed on the role of sulfur in green plants and also on the very close interdependence of plant metabolism, sulfur assimilation and sulfur dioxide tolerance levels. The fluctuations of foliar sulfur content in healthy vegetation are described in light of frequent use, by research workers, of foliar sulfur content as a damage index parameter. An attempt is made to clearly distinguish between controllable and uncontrollable factors that cause sulfur dioxide damage in forest vegetation.

2. SULFUR REQUIREMENTS IN PLANTS

Sulfur is an essential element in plant metabolism, and in many structural components of plants. Sulfur is usually absorbed by the roots as sulfate ion, but may also enter the leaves as gaseous sulfur dioxide, or dissolved in water as sulfurous acid (Syratt, W.J. et al 1968). Most sulfur atoms undergo valency changes from +6 to -2 prior to incorporation into organic form in a process called "assimilatory reduction". However, many active organic sulfur compounds are found in the +6 valency state, as sulfate. In the reduced state of -2, sulfur is an important constituent of all proteins, structural as well as metabolic, as part of the molecular structure of the amino acids cystein, cystine and methionine. For protein synthesis alone, sulfur is required in rather large amounts. Sulfur is found in the vitamins thiamin and biotin. It is also the major element in the backbone of ferredoxin, a sulfur-iron-protein complex which functions in the electron transfer system in photosynthetic reactions, and in nitrate and nitrate reduction (Mahler and Cordes 1966).

Green plants possess complex enzyme systems to reduce and assimilate both atmospheric sulfur dioxide and sulfate ion in aqueous solution. In healthy leaves sulfur contents should range from 500 - 14,000 ppm by dry weight (0.5 - 14 mg per gm of dry weight) depending on species (Treshow 1970). Concentrations below 250 ppm are considered critical, and give rise to deficiency symptoms, and to the substitution of selenium for sulfur in sulfur aminoacid and protein synthesis (Treshow 1970).

3. THE INFLUENCE OF FACTORS OF THE ENVIRONMENT ON PLANT METABOLISM, ON SULFUR DIOXIDE ASSIMILATION AND ON SULFUR DIOXIDE TOLERANCE LEVELS

Sulfur dioxide is readily assimilated by green plants, provided a threshold rate of gas application is not exceeded. This threshold rate is not a fixed value, but depends on fluctuating sulfur dioxide tolerance levels of plants. Any combination of at least twelve environmental factors induces fluctuations in sulfur dioxide tolerance levels. These same environmental factors induce fluctuations in rates of plant metabolism and sulfur assimilation (Linzon 1971). In general, there exists an inverse relationship between the rate of plant metabolism and sulfur dioxide tolerance levels, whereas fluctuations in rate of plant metabolism and sulfur assimilation are in phase in the presence of atmospheric sulfur dioxide. In other words, conditions that favour good plant growth, increase the capacity of the plant to assimilate sulfur dioxide, but reduce the plant's tolerance to this gas.

None of the environmental factors that influence sulfur dioxide tolerance levels can be controlled in unmanaged forests. Sulfur dioxide tolerance levels are low under the following conditions:

1. high light intensity both before and during fumigation. (Davies 1969, Rohmeder *et al* 1965)

2. high temperature (Daines 1969)

3. daylight (Daines 1969)

4. growing season (Daines 1969)

5. high relative humidity (Syratt _et al_ 1968, Thomas _et al_ 1956, Daines 1969).

6. water on leaves (Costonis 1971)

7. high soil moisture (Daines 1969)

8. old plants (Daines 1969)

9. low vigour due to insects or diseases

10. low nutrition levels (Faller _et al_ 1970, Enderlein _et al_ 1967)

11. susceptible species (Scheffer _et al_ 1955, Dreisinger _et al_ 1970)

12. genetic factors within species (Boertitz 1964, Boertitz _et al_ 1969, Dochinger, 1968)

Several workers developed mathematical formulae to calculate threshold rates in terms of gas concentrations and durations of exposure to symptom development. Their assumptions were that all the above environmental factors were constant.

4. SYMPTOMATOLOGY OF SULFUR DIOXIDE INJURY

Fumigation of trees with sulfur dioxide, generally induces typical changes which results in altered leaf function, colour and form. These may, over several days or weeks, result in changes in growth and development. Together, these changes constitute a complex of symptoms, and their study is termed symptomatology.

A great variety of factors can affect the rate and extent of symptom expression and many factors may independently produce some of these symptoms, making positive diagnosis complex and dependent on wide knowledge. Furthermor

under some conditions, changes may take place that in themselves are not damaging, but predispose the tree to damage from other causes occurring either simultaneously or subsequently.

(a) Gross visible effects

As sulfur dioxide enters the needles of conifers or the leaves of broad leaved trees, it dissolves in water and forms sulfurous acid. As described earlier, if the rate of entry is very low, the sulfur can be metabolized in a normal way and no symptoms develop. If sulfur in excess of the tree's requirements enters slowly, it eventually causes a slowly-developing (chronic)* injury, characterized visibly by a general chlorotic (yellow) appearance.

If, however, sulfur dioxide enters too rapidly, the tree's systems for coping with sulfur are overwhelmed and acute damage occurs. Affected leaves first appear water-soaked and straw coloured, the symptoms generally beginning at the tips of needles of conifers or the margin of broad leaved trees. In conifer needles, symptoms proceed towards the point of attachment, whereas in broad leaved trees, the intercostal leaf areas are affected shortly after the marginal areas. The affected areas soon dry out and gradually become reddish brown and brittle (necrotic or dead). Commonly, symptoms are more severe on the side of the tree facing towards the emission source.

Repeated fumigations may injure previously unaffected portions of partially damaged needles, resulting in a banded appearance of the necrotic portions. Severe fumigation will also affect the veinal areas of leaves of broad leaved trees. Trees are killed by severe fumigations when not only

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*chronic and acute relate to the morbidity status of the tree and not to disease stages.

the leaves but also next year's buds are killed.

The gradual appearance of chronic symptoms as a result of continuous, low-level exposure, may be parallelled by intermittent sub-acute fumigations of shorter duration. Both of these have the effect of shortening needle life and needle retention, although not as markedly as acute fumigations. Unaffected needles are normally retained for three to five years. In areas of continuing fumigation, retention is reduced to one to two years (Boertitz 1964, Boertitz 1969). This reduces tree growth and results in diminished terminal growth, shorter twigs and internodes, smaller needles, and in narrower growth rings; these can act as aids for diagnosis and measurement of injury.

Sub-acute fumigations, during the period of needle expansion, may similarly retard growth of that year's needles. The result is that twigs bear needles of variable lengths. This is called the "big-little needle" symptom, and is quite common in areas subjected to sulfur dioxide emissions.

In broad leaved trees, chronic injury results in chlorosis of leaf tissues in small flecks, mottled, or diffuse, and finally in a general yellowing of the entire leaf (Dochinger 1971).

(b) Microscopic effects

Damaged needles commonly show dead or necrotic brown zones, a transition zone of yellowish to reddish colour, and a zone of green, apparently unaffected tissue. Sulfur dioxide does not produce "hidden damage" in green plant tissue (Katz 1949). However, internal tissue changes that have diagnostic value are evident in the transition zones of affected needles. Changes occur in the undifferentiated parenchyma cells as a result of fumigation with sulfur dioxide (C.C. Gordon, personal communication).

(c) Physiological effects

Sulfur dioxide fumigations have temporary effects on the relative concentrations of intermediary metabolites including non-sulfur containing compounds. As was mentioned earlier, however, there is to date no evidence of hidden sulfur dioxide damage in green tissue. The development of visible symptoms such as the yellowing of foliage, is associated with the breakdown of chlorophyll molecules and accessory pigments such as carotene and xanthophylls. (Mamaev et al 1969).

5. FOLIAR SULFUR CONTENT AS A DAMAGE INDEX PARAMETER

Foliar sulfur levels fluctuate in healthy leaves. Katz (1949) stated: "Unless the concentration and exposure to gas and other (environmental) factors are known accurately, there is no quantitative relation between the increase in sulfur levels of plant tissue and the degree of injury, because the sulfur content is subject to great variation in normal plants". Many workers in the 60's and 70's confirmed Katz's conclusions, that foliar sulfur levels are not related to damage by sulfur dioxide. Some of these are Berry, G.R. et al 1964, Viel, M.G. et al 1965, Garber, K. 1960, Wentzel, K.F. 1968 and Bjorkman, E. 1970. Guderian 1970 (b) found that sulfur levels continue to fluctuate in the green photosynthesizing tissue of partially killed needles, whereas sulfur levels remain steady in the killed portions of such needles. Guderian further reported that foliar sulfur levels decrease after cessation of fumigations, and are therefore not only dependent on rates of sulfur assimilation during fumigations, but also on frequency and duration of sulfur dioxide free periods between fumigations. Hence the timing of sampling for sulfur level determinations after exposure to sulfur dioxide becomes an additional variable factor. There is another

complicating factor. Long periods of uninterrupted exposure to very low levels of sulfur dioxide cause greater increases in foliar sulfur levels than shorter periods of exposure to higher but still sublethal levels of sulfur dioxide (Guderian 1970 (a).

It is clear that foliar sulfur contents cannot be used as a measure of damage by sulfur dioxide. However, given a steady source of sulfur dioxide emissions, as found in sour gas plants, foliar sulfur levels will be indicative of the extent of sulfur dioxide dispersion. Katz (1949) noted: "Nevertheless, such data (foliar sulfur contents) from comprehensive collections of certain sensitive plants, may be used to define the area within which the gas occurs". Today, this is indeed the only "practical" use that can be made of knowledge of foliar sulfur contents obtained from field samples.

Results of a co-operative study of the Alberta Forest Service and the Provincial Air Pollution Control Division showed that pine and spruce foliar sulfur contents fluctuated upwards in the vicinity of sour gas plants for three to five years, after which they fluctuated down again to levels found at the time the gas plants went into production, whereas foliar sulfur contents of aspen and poplar continued to fluctuate upwards (Ullman 1967). From a biological point of view, the fluctuations in foliar sulfur levels in pine and spruce after three to five years exposure to sulfur dioxide may be ascirbed to any of the uncontrollable factors of the environment which were listed above and about which we have no information. From a practical point of view, sulfur dioxide emissions near the sour gas plants investigated by these agencies have up to now obviously been below the tolerance level for the main tree species.

6. SULFUR DIOXIDE AT THE STACK AND IN THE ENVIRONMENT

(a) Controllable factors

The amount of sulfur dioxide released into the environment depends on the following factors that can be controlled:

i) The efficiency and reliability of installed pollution abatement equipment

Control of pollution at the source by means of the "Best Practicable Technology" approach, is the strategy recommended by Federal Authorities (Lucas, 1971). Operating limitations of sulfur recovery units in gas plants result in 0.5 - 1 per cent below theoretical recovery rate after initial start up, and will decline further to 1.5 per cent before the catalyst is replaced because of catalyst deactivation (Klemm, 1972).

ii) The rate of production

Once the sulfur recovery efficiency of an individual gas plant is known, the rate of production is the principal controllable factor determining rates of sulfur dioxide emission from the stack.

iii) Numbers of gas plants per unit area

Potential increases in numbers of gas plants depend on the discovery of new large fields. Amounts of sulfur dioxide releases into the environment can be controlled by limiting the numbers of gas plants with known production rates and sulfur recovery efficiencies, per unit area. (Tollefson, 1972). Extensive sulfur dioxide damage to forest vegetation has been associated with the mining

industry of the Sudbury region of Ontario. Sudbury is an example of too many sulfur dioxide effluent sources per unit area. There are 18 mines and 9 reduction plants, managed since 1888 by the International Nickel Company of Canada and the Falconbridge Nickel Mines. It is estimated that about two million tons of sulfur dioxide are emitted annually in the Sudbury area alone (Leblanc, Fabius et al 1972, Linzon, 1971 (a)).

iv) The rate of dispersion of stack effluent

The rate of dispersion of stack effluent cannot be controlled, but can be influenced by the proper selection of plant location and by effective stack height. Trail, British Columbia, is an example of the importance of topography on effluent dispersion. In Trail, Consolidated Mining and Smelting Company operates smelters that are situated in the Columbia Valley, which functions as an extended chimney. Stack effluents are not emitted randomly, but drift daily down the same areas. Reductions in growth rates were most pronounced in the vicinity of steady emission sources, but recovery to increased growth rates were noted in trees in the vicinity of reducing plants after the installation of pollution abatement equipment or plant closure (Katz 1939).

(b) Uncontrollable factors

i) Emergencies

Human error, mechanical failure or flaring during plant upset, may temporarily elevate sulfur dioxide concentration in the forest to above-threshold-levels. Since ground level concentration standards for flaring in Alberta (Anonymous 1970) are above the threshold level for jack pine, white spruce, trembling aspen, balsam poplar, white birch and larch, (Dreisinger *et al* 1970) (Table I), flaring during the growing season and in calm, humid and warm weather, may severely damage or kill well defined areas of forest vegetation. Possible synergistic effects of sulfur dioxide with other components of the effluent may be damaging.

ii) Weather conditions

Prolonged spells of severe cold may reduce sulfur recovery in gas plants by a significant amount of theoretical recovery rates and hence could constitute additional hazard.

Controlled rates of sulfur dioxide emissions at the stack are diluted in the atmosphere by the following uncontrollable and highly variable weather conditions.

i) windspeed
ii) wind direction
iii) temperature inversions
iv) relative humidity
v) precipitation
vi) mechanical and thermal air turbulence factors

Sulfur dioxide concentrations will therefore fluctuate from minimal, below-threshold-concentrations, to maximal, above-threshold-concentrations.

It is well established that plumes from stacks may retain their integrity for long distances during certain types of weather conditions. These plumes frequently impinge upon the ground surface at different distances from the stacks. Vegetation damage frequently results within these impingement areas which may encompass several square miles or more in area.

7. PROBLEMS ASSOCIATED WITH MONITORING OF ATMOSPHERIC SULFUR DIOXIDE

There are two basic problems in monitoring that must be understood:

1. In forests surrounding sulfur dioxide emission sources, sulfur dioxide concentrations will fluctuate constantly at any given point in the three dimensional space occupied by forests. In absolute terms, an atmospheric sulfur dioxide concentration is unique for a specific location, and for a specific, very short period of time. Hence data obtained from a monitoring station must be extrapolated with caution to locations outside the micro environment occupied by the monitoring device.
2. For the biologist, monitoring for atmospheric sulfur dioxide becomes meaningful when locations, concentrations and durations of lethal fumigations can be identified. Plants may be killed, either partly or completely when subjected to lethal concentrations of sulfur dioxide for short periods of time. Exposure cylinders will only provide information on cumulative amounts of

sulfur dioxide which can be averaged for numbers of hours or days of exposure, and are therefore of very limited use. Monitoring devices of the continuous monitoring type are essential for meaningful surveillance. These systems entail considerable cost, and must be placed in strategic positions which take into account differences in effluent concentration with height above ground as well as the principal plume impingement areas.

8. THE GREEN PLANT AS A MONITORING DEVICE FOR ATMOSPHERIC SULFUR DIOXIDE

Sour gas plants release known and controlled amounts of sulfur dioxide from the stack. Rates of effluent dispersion and sulfur dioxide effects on vegetation are determined by the cumulative effects of large numbers of interacting variables, none of which can be controlled. However, the green plant itself reflects the sum total effects of biotic and abiotic interacting variable factors of the environment. The green plant itself can therefore function as a monitoring device, and can serve as an indicator of the state of health of forests surrounding gas plants.

Plant species show a wide range of sensitivity to atmospheric sulfur dioxide. Among the most sensitive species are mosses and lichens (Leblanc 1971, Leblanc 1969, Gilbert 1968).

Short-term studies of short-term sulfur dioxide effect may be conducted by transplanting lichens into polluted zones, and recording the time required for the lichens to die. Results of such studies have shown that survival times near steady emission sources are minimal, but increase with increasing distances from such sources (Kirschbaum _et al_ 1971, Leblanc _et al_ 1966, Schoenbeck 1968).

Short-term studies of long-term sulfur dioxide effects involve the evaluation of lichen luxuriance and numbers of species in pre-selected sites. Modifications of this approach include the construction of an Index of Atmospheric Purity (Leblanc, Fabius et al 1972), the construction of detailed distribution maps of selected lichen species (Skye, Erik 1968), and the construction of a qualitative sulfur dioxide air pollution scale (Hawksworth, D.L. and F. Rose 1970). The results of these and other (Smith, C.W. 1968, Barkman, J.J. 1968, Gilbert, O.L. 1968) studies consistently showed that numbers of species decrease with decreasing distance to the emission source. A few anomalies were noted, where species of lichens were found in pockets inside areas otherwise denuded of these species. Such areas were believed to be sheltered from sulfur dioxide gas due to topography and surrounding vegetation which acted as buffer zones (Gilbert, O.L. 1970).

Meaningful biological monitoring systems can be developed when the specific functions and values of forests surrounding emission sources have been determined. Criteria of injury relating to a variety of resource use allocations have been summarized (Knabe 1971, Guderian et al 1960).

9. AMBIENT AIR QUALITY STANDARDS AND THE FOREST

In Alberta, the maximum acceptable ground level concentration standards for sulfur dioxide in forested areas are as follows: (Anon 1970)

(a) 0.30 ppm for 30 minutes

(b) 1.0 ppm for less than one hour for a short period of emergency flaring

The ambient air quality standards for Alberta in forested areas are as follows:

(a) 0.30 ppm for one hour

(b) 0.10 ppm for 24 hours

Dreisinger et al (1970 published minimum average concentrations of sulfur dioxide in ppm at which injury occurred (Table I).

Table I

Minimum average concentrations (in ppm) at which injury occurred (Adapted from Dreisinger et al 1970). Ground Level Concentration Standards (G.L.C.S.) and Ambient Air Quality Standards (A.A.Q.S.) (Anonymous 1970).

Species	30 min	< 1 hr	1 hr	2 hrs	4 hrs	8 hrs	24 hr
			ppm				
Trembling aspen			0.42	0.39	0.26	0.13	
Jack Pine			0.52	0.44	0.29	0.20	
White birch			0.46	0.38	0.28	0.21	
Larch			0.41	0.38	0.34	0.26	
Balsam poplar			0.82	0.65	0.45	0.26	
White spruce			0.87	0.79	0.70	0.50	
G.L.C.S.	0.30	1.0					
A.A.Q.S.			0.30				0.10

A comparison of ground level concentration standards and threshold concentrations of sulfur dioxide for the species listed, all of which occur in Alberta, shows that 1.0 ppm for less than one hour, permitted during flaring, will injure Alberta forest species. All the other standards are below the threshold level of Alberta trees, but populations of the most sensitive plants, such as lichens and bryophytes will undoubtedly be killed. It has been

reported that the most sensitive species of lichens are unable to survive in areas where average annual sulfur dioxide levels are greater than 0.011 ppm, and no lichens survive in areas where annual concentrations of sulfur dioxide exceed 0.035 ppm (Gilbert 1968).

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FILE REPORT NOR-Y-73

R. A. Blauel (1973)

COMMENTS ON THE VEGETATIVE SECTION OF THE CANADIAN PETROLEUM ASSOCIATION'S SUBMISSION TO THE ENVIRONMENT CONSERVATION AUTHORITY, ALBERTA DEPARTMENT OF THE ENVIRONMENT, EDMONTON, ALBERTA.

Northern Forest Research Centre
Canadian Forestry Service
Environment Canada
Edmonton
Jan. 1973

INTRODUCTION

The Canadian Forestry Service was requested by the Environment Conservation Authority, Alberta Department of the Environment, to comment upon the contents of the vegetative section of a submission entitled "Environmental Effects of the Operation of Sulphur Extraction Gas Plants" and dated September 1972, a d submitted to the Board by the Canadian Petroleum Association. The Canadian Forestry Service comment is contained herein.

COMMENTS

Readers of the Submission would have benefitted by some description of the modes of action by which sulphur dioxide injures plant tissues. To serve this purpose the following summarizes what is currently known.

Haselhof and Lindau (1903) reported that sulphur dioxide was bonded to aldehyde groups and that plant tissues were injured by the degradation of these compounds into sulphuric or sulphurous acid. Novak (1929) postulated that sulphur dioxide caused inactivation of iron in the chloroplasts which prevents the assimilation of organic compounds. Dorries (1932) stated that the interaction of acidic compounds resulting from sulphur dioxide split magnesium from the chlorophyll compound, changing it into a phenophytin and blocking the photosynthetic process. Thomas (1951) attributed the onset of acute injury symptoms to the excessive accumulation of either sulphite or sulphurous acid in plant tissues. Nikolavesky (1968) found that sulphur dioxide inactivated catalayse and increased both peroxidase and polyphenol-oxidase. Another report (Anonymous 1968) stated that hydrogen sulphide was formed from sulphur dioxide in the foliage, and this caused injury. Ziegler (1972) recently suggested that sulphur dioxide competes with carbon

dioxide for reaction sites and consequently interferes with photosynthesis. Wellburn (1972) has shown that sulphur dioxide causes swelling of the thylakoids within the chloroplasts and this damages them.

The harmful effects of air pollutants were separated by Guaderian (1960) into two distinct categories, 1) injury: the response of the plant 2) damage: the impairment of economic value. Knabe (1971) has established criteria by which harmful effects may be evaluated. In Tables 1 and 2 a modified form of this criteria is used to present the effects of sulphur dioxide on trees and forest communities that have been either reported in the literature or observed in the field by the author. These tables reflect a degradation in the condition or quality of the plants as they have deviated from their normal and do not express a comparison to a specific standard.

The phenomena which influence the effects of sulphur dioxide and other air pollutants on vegetation are summarized as follows:

1) The actual composition of the pollutant.

   A combination of gases can result in possible synergisms and predispositions or resistances.

2) The rate at which the pollutant reaches the receptor.

   This rate includes the concentration and quantity of the pollutants; and the interval and frequency at which the receptor is exposed.

3) The physical and physiological tolerance of the plant species to the pollutant as determined by genetic makeup.

4) The general vigor or health of the plant as a function of its ability to take stress.

5) The maturity and type of plant tissue the pollutant impinges on.

6) A wide variety of climatic conditions which strongly affect plant sensitivity both before and during exposure to the pollutant. These

factors include the qualitative and quantitative characters of light, temperature, wind, humidity and moisture. Loman et al (1972) provides a summary of conditions where tolerance levels are low.

7) Edaphic qualities such as soil moisture, acidity and nutritional availability.

In conclusion "conditions that favour good plant growth increase the capacity of the plant to assimilate sulphur dioxide, but reduce the plant's tolerance to this gas" (Loman et al 1972).

The Canadian Petroleum Association Submission makes reference to numerous studies which have been conducted on the variation in sensitivity of plants to sulphur dioxide gas. In each of these studies, only a few of the factors which affect sensitivity were chosen and tested as variables, with the other factors treated as constants. Examining the results of these studies out of context with the other variable factors results in an extremely attenuated picture regarding plant sensitivity rating, and some of the data presented in the submission strongly reflect this (e.g. Table 11 - 2 and Table 11 - 3).

The Submission contains reference to the sulphur dioxide sensitivity of the higher plants only, and disregards lower plants in the lichen and bryophyte groups which occur in abundance in all of Alberta's forest communities. These lower plant groups are much more sensitive to sulphur dioxide, with the lichens known to be damaged or eliminated from areas in England where constant annual concentrations of sulphur dioxide are around .02 ppm. (Mansfield and Bull 1972). Leblanc (1971) gives the following reasons for the lichen sensitivity to sulphur dioxide: 1) a high non selective capacity for accumulating substances from the atmosphere. 2) a low potential for

recovery after fumigation because of limited metabolic rates due to low chlorophyll content. 3) perennial evergreen habit. 4) lack of devices to close off gas transfer (the higher plants have specialized structures such as stomata which perform this task).

The sulphur dioxide concentration limits that are suggested in the Submission for Alberta are open to question. The evidence presented shows that damage does occur to Alberta plant species under the concentration limit recommended in the Submission. Dreisinger and McGovern's data from Sudbury, Ontario shown in Table 11 - 4 shows that damage did occur under .75 ppm. for 1 hr., during undefined environmental conditions to the following forest species which are native to Alberta: trembling aspen, jack pine, large toothed aspen, white birch, larch, willow and alder; and the following Alberta crop species: barley,(missing from the table but included in Dreisinger and McGovern's 1970 presentation of the paper), oats, red clover, peas, rhubarb, timothy, lettuce, radish, squash, tomatoes, potatoes and raspberry. Wheat is not on the list of vegetation that Dreisinger and McGovern observed, but others have reported that it is a relatively sensitive species (e.g. Table 11 - 3 of the Submission lists it as such).

The environmental factors which control the susceptibility of vegetation to sulphur dioxide were not reported in the evidence used in the Submission . Extrapolation of the "safe ground level concentrations and durations" from the data presented in the Submission to Alberta can be seriously questioned on this basis.

TABLE 1

INJURY CAUSED BY SULPHUR DIOXIDE AIR POLLUTION TO TREES AND FOREST COMMUNITIES

Criteria of effect	subject of investigation				
	part of a plant	individual plant	number of individuals	population (stand)	ecosyst
changes in cell components:	x	x	x	Na	Na
changes in metabolism	x	x	x	Na	Na
changes in cell structure	x	x	x	Na	Na
degree of foliar chlorosis or necrosis	x	x	x	Na	Na
premature foliar dropage	x	x	x	Na	Na
inhibited foliar growth	x	x	x	Na	Na
inhibited terminal growth	x	x	x	Na	Na
inhibited increment growth	x	x	x	Na	Na
predisposition to other stresses	x	x	x	Na	Na
plant death(s)	Na	x	x	Na	Na
percentage of plants injured to a certain degree	Na	Na	x	x	x
percentage of dead plants	Na	Na	x	x	x
decreased production of organic matter or decreased increment per area	Na	Na	Na	x	x
changes in number of species	Na	Na	Na	x	x
changes in abundance	Na	Na	Na	x	x
changes in coverage	Na	Na	Na	x	x
changes in general health conditions	Na	Na	x	x	x

x = detrimental changes have occurred

- = no changes have occurred

Na = not applicable to the category

TABLE 2

DAMAGE CAUSED BY SULPHUR DIOXIDE AIR POLLUTION TO TREES AND FOREST COMMUNITIES

Impairment in economic value	Subject of investigation				
Trees	part of a plant	individual plant	number of individuals	population (stand)	ecosystem
by reduced fiber yields					
a) wood fiber formed before pollutant release	Na	-	-	-	Na
b) wood fiber formed during pollutant release	Na	x	x	x	Na
by reduced quality of foliage					
(shelterbelts, ornamentals and Xmas trees)	x	x	x	x	Na
by decreased resistance to biotic and abiotic influences (e.g. bark beetles, frost)	x	x	x	x	x
Forest communities					
by increase of forest pests	Na	Na	Na	x	x
by reduced recreational value	Na	Na	Na	x	x
by reduced watershed value	Na	Na	Na	x	x
by reduced wildlife habitat	Na	Na	Na	x	x
by alterations in forest influences (e.g. filter capacity)	Na	Na	x	x	x
impairment in ideal value	x	x	x	x	x

x = detrimental changes have occurred

\- = no changes have occurred

Na = not applicable to the category

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Special Appendix to
Science Advisory Committee Critique

Some pertinent quotations concerning resource and evironmental economics from the recent text entitled Economic Growth and Environmental Decay; the Solution Becomes the Problem, by Barkley and Seckler (12).

Implied in the above remarks is a divison of man's total environment into two categories--that which is controllable and that which is not. It is of extreme importance to understand that this distinction is purely conceptual. In reality, any environment is a tightly connected system. Because of this tight connectedness or interdependence, every act of choice or every manipulation of the environment sets off chains of repercussions, often uncontrollable, through the entire environmental system. For example, who, in the wildest flight of fantasy, could have predicted the consequences of an innovation so apparently innocuous as the automobile. Yet, the automobile has disrupted families, poisoned the air, changed moral standards, moved whole populations off the land into the cities, destroyed the wilderness, and impoverished many who feel compelled to purchase these expensive machines. The automobile is quite ordinary as a device for moving people from place to place, but few inventions of man have had such profound social and environmental effects. The *intended* consequences of the automobile are quite admirable. Its *unintended* effects are pervasive and often highly destructive. *Environmental economics is the study of the unintended consequences of choice.* pp. 3-4.

Choice not only determines man's immediate welfare, it also determines the various options open to him in the future. For this reason it is essential that man choose well, that he take into account not only the immediate, intended consequences of his choices, but the long-range, unintended consequences as well. He must ask himself where he is going and if existing technology, values, and institutions will lead him there. p. 4.

Because one never gets something for nothing, difficult choices must always be made. If an adequate level of environmental quality is to be restored and maintained, some conventional economic commodities will have to be given up. If the freedom to choose the kind of environment in which people want to live is to be preserved, the freedom of choosing to destroy the environment must be curbed. In sum, every choice brings benefits only at the expense of certain (often unanticipated) costs. It takes a great deal of thought and foresight to know whether as a whole and in the long run the benefits of any particular choice outweigh its costs. Determining the benefits and costs of choices is a central problem for those who wish to study the relationship between economic growth and environmental decay. p.7.

* Italics are those used by the authors of the text cited.

[illegible] raise [illegible] basis for the affluence of the modern world. Few need to question the value of the economic growth which has brought the American and many other economic societies out of poverty. But the costs and benefits of [illegible] economic growth in a *prosperous* age are topics that should be seriously examined. p. 16.

One of the fundamental concepts of economics is *opportunity cost*. When choices are made, one course of action is accepted while another is denied or rejected. The rejected course is the "cost" of the accepted choice. If steel is used for building bridges rather than for making ships, the nonproduction of ships represents the opportunity cost of the bridges. The ships are the benefit that has been foregone. The concept of opportunity cost, however is not limited to things that can be measured in dollars and cents. For example, if a student must choose between studying and going to the movies, he experiences costs and benefits no matter which choice is made. If he decides to study, certain benefits are received and these must be weighed against the opportunity for pleasure given up by staying home. Similarly, if the choice is to go to the movies, the consequent benefit must be balanced against the costs of not having studied. Such decisions are difficult to make because a wrong decision is always possible--the costs may exceed the benefits. pp. 35-36.

One particularly upsetting failure of a market-oriented economic system is commonly known as an external effect or externality. There are several other names for these effects. They can as well be called uncompensated effects, third-party effects, or simply non-market effects. External effects and externalities will be used here.

In every economic transaction, one party incurs costs in order to receive benefits. The other party receives payments and gives up goods or services. This demonstrates interdependence and closes the feedback loop. In an ordinary transaction, the purchaser is expected to pay the full cost of the item, and he expects to get full and sole claim to its use. For example, a homemaker who buys a loaf of bread expects to pay the full cost and to get the full enjoyment from consuming it. Unfortunately, the feedback loops in economics do not always close this completely or this surely. Sometimes those who pay the costs do not receive all the benefits; and sometimes the payments made for an item do not cover all the costs of producing it. An example of the first type is the man who sprays his swampy backyard so mosquitos will no longer breed there. His neighbours receive some benefits even though they have not contributed any payments. An example of the latter condition is the factory that dumps raw industrial waste into a nearby stream. It is not paying all the costs of its doing business.

In either of these instances, the system may be described as being inefficient. In the first case (the payer not receiving all the benefits), it is likely that not enough of the product is being produced. If each [illegible] for his share of the benefits more funds would have been available to spray other yards. When such assessments are not or cannot be made, the system does not produce enough of the product or service (mosquito abatement). In the second case, the system may be producing too much of the product. If the factory had to pay all the damages created through its polluting activities, its cost of production would rise, and its products would have to sell at higher prices.

Many of the most common problems of environmental quality can be traced to some variation of the problem of external effects. Air and water pollution stem from the fact that automobile owners, industrialists and municipalities can avoid many costs associated with waste disposal by simply dumping their refuse into the atmosphere or into waterways. Lumbering companies can cut trees without having to pay those who prefer to leave the trees standing and who, therefore, suffer a loss when forests are cut. On the other hand, no single individual wishes to pay for clean air because he would have to clean up all the air for everyone. Everyone will share in the benefits of his purchase, but few will be induced to help him pay for it.

All external effects have two properties: interdependency--one person's behavior creates a cost or benefit to other persons; and lack of compensation--the one who creates cost is not made to pay for it, nor is the one who creates the benefit completely rewarded for it.

With this in mind, the desired relations of exchange and the unintended relations of externalities can be shown. A producer and a consumer regulate each other through the supply and demand mechanisms of the market, as shown in Figure 1. But the producer creates other effects, smoke and noise, affecting the welfare of a group of citizens who do not consume the product of the firm. There is no corresponding arrow of influence through which these citizens can regulate the producer's effects. Therefore, the producer and consumer will reach an equilibrium position different from that which would be optimal were all affected citizens' interests taken into account.

A realistic and more equitable solution to this problem could be achieved through a government agency receiving complaints from the affected citizens and transforming these inputs into regulatory intervention (taxes, subsidies, laws, or regulations) into the producer's affairs. The feedback loop would then be closed through the path affected, citizens ⟶ government ⟶ producer, and a more nearly optimal state would be attained. The producer is now forced to include the interests of those who suffer from smoke and noise in his decision-making process. pp. 99-102.

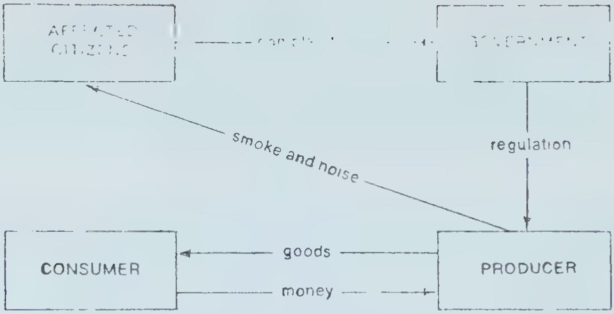

Figure 1. After Barkley and Seckler.

If the reader suspects an intimate connection between collective goods and externalities, he is quite right: the major kinds of externalities involve the expropriation of collective goods for private use. To review, [illegible] affected parties are not considered. It applies to both private and collective goods and may be either good or bad. A farmer uses a stream for [illegible] has certain aesthetic and recreational qualities that can be simultaneously enjoyed by many people (a collective good); a farmer diverts this stream from recreation uses without paying [illegible] (a collective [illegible]-nality).

In an analytic sense, collective and private good externalities are the same. They are both expropriations. However, the more serious problem of market failure due to externalities affects collective goods. While there is a pattern of incentives and laws to mitigate private good externalities, no parallel structure governs collective goods. Returning to the example of the stream, the first farmer receives substantial benefits from his use of the stream. Moreover, these benefits accrue solely to him. So when the second farmer attempts to divert the water, the first farmer is strongly induced to protect his vested interest. If the law fails to arbitrate disputes of this nature, it is not unusual for the matter to be settled on the basis of force. In Colorado, for example, there were shotgun allocations of water as late as 1965 (and perhaps later).

Contrast this with the state of the recreationist who uses the stream two or three Sunday afternoons each year. There may be a great many people like him, and the sum total of the benefits they enjoy from the stream in its natural state may greatly exceed the benefits of that water in irrigation. But no one has an interest in the stream comparable to that of the farmer. The result is that no individual enjoying the natural stream is provoked to go to great trouble and expense to protect it from diversion; by contrast, the person benefiting from its private use for irrigation has strong inducement. Even if there are a few strongly

[illegible] the [illegible] of [illegible] effectively [illegible]. In the end it is a question of whether or not feedback [illegible] over [illegible]. It is a question of social [illegible]. Externalities [illegible]. What determines their seriousness [illegible] durability is the [illegible] to which free riders can operate. pp.136-137.

As was mentioned at the outset, a study of environmental problems is the study of unintended consequences of choice. Although the [illegible] aspects indeed remain, they need not be unrecognized. Recognition of side effects, evaluation of tradeoffs or compromises, and analysis of alternative paths of action are the skills that the economist can bring to the study of contemporary problems confronting man and nature. p.185.

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Public Hearings on Land Use and Resource Development in the Eastern Slopes
June - July, 1973

Information Bulletin Number 1:	Terms of reference.
Information Bulletin Number 2:	Current Status Report on Alberta's Eastern Slopes.
Information Bulletin Number 3:	Information Centres and Source Material.
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Information Bulletin Number 5:	Planning Statement - Oldman River Regional Planning Commission.
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